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Probiotic microorganisms- identification, metabolic and physiological impact on poultry

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The increase in the productivity of the poultry industry has been accompanied by various impacts, including the emergence of a large variety of pathogens and bacterial resistance to antibiotics. These impacts are in part due to the haphazard use of chemotherapeutic agents as a result of management practices during the rearing period. Probiotic bacteria are defined as live microorganisms that, when administered in adequate amounts, confer a health benefit on the host. This paper provides a review of the use of probiotics for the prevention of enteric disease in poultry, probiotic selection, isolation, colonisation and attachment within gastrointestinal tract, and the potential role of probiotics in nutrient metabolism. Understanding how probiotic bacteria exert their beneficial effect is crucial for the establishment of definitive selection criteria.

Keywords: probiotics; chicken; characteristics; gastrointestinal tract; nutrient metabolism

Introduction

Bacterial antimicrobial resistance in the medical and agricultural fields has become a serious problem worldwide. Antibiotic-resistant strains of bacteria are an increasing threat to animal and human health, with resistance mechanisms identified and described for all known antimicrobials currently available for clinical use. There is currently increased public and scientific interest regarding the administration of therapeutic and sub-therapeutic antimicrobials to animals, due primarily to the emergence and dissemination of multiple antibiotic-resistant zoonotic bacterial pathogens (McDermott *et al.*, 2002). Social pressures have lead to the creation of regulations to restrict antibiotic use in poultry and livestock production. There is a need to evaluate potential alternatives to prophylactic antibiotics to improve disease resistance in high intensity food animal production. Nutritional approaches to counteract the debilitating effects of stress and infection may provide producers with useful alternatives to antibiotics. Improvements in disease resistance of poultry raised without antibiotics will not only benefit the poultry' health, welfare and production efficiency but can represent a key strategy in the effort to

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improve microbiological safety of poultry products. Recently, interest in the use of probiotics to improve performance and the general health status of all poultry species, particularly broiler chickens and layer hens, has been revived by legislation to curtail the use of sub-therapeutic doses of antibiotics in poultry diets.

Probiotics are classified as zootechnical feed additives (European Commission, 2003) and comprise a functional nutritional approach, whereby the maintenance of a healthy gastrointestinal environment and improved intestinal function is pursued through the intake of sufficient quantity of live, beneficial microorganisms (FAO/WHO, 2002).

The populations of microorganisms found within the gastrointestinal tract (GIT) of poultry can be divided into two classes. The first, the autochthonous bacteria, colonise the gut by inoculation resulting from environmental exposure and normal feeding activities of the bird (Gusils *et al.*, 1999). The second, allochthonous bacteria, are exogenous in nature and are introduced as a dietary supplement into the GIT through the feed or drinking water as direct fed microbials (DFM) or probiotics (Patterson and Burkholder, 2003). Typically, nutritionists use the terms probiotics and DFM interchangeably. Some data in the literature indicate that allochthonous bacteria introduced via probiotics may prevent infection and colonisation of the GIT by opportunistic pathogens (Fuller, 1989). Introduction of probiotics is believed to prevent or attenuate the growth of clinical enteric pathogens in poultry, resulting in enhanced growth and performance of the host bird. This phenomenon has prompted a widespread interest in the poultry industry of probiotic usage as an alternative to the prophylactic use of antibiotics for the prevention of disease within poultry flocks (Salminen *et al.,* 1998). This interest has arisen as the result of growing concerns about prophylactic usage of antibiotics in poultry and other animal production systems in Europe and the US (Davis and Anderson, 2002; Mai, 2004).

A number of probiotics are available on the market under different trade and commercial names. Probiotics are a combination of organisms that have been deemed beneficial and which are adaptable to the intestinal mucosa of all warm blooded animals. However, the primary bacterial organism present is *Lactobacillus acidophilus*, which implants itself on the villi of the intestinal wall in large numbers, thereby creating an acid environment through the nature of the organism, which grows best at a pH of 5.0 to 6.5 (Mahmood *et al.*, 2005). Implantation via an effect called 'crowding' begins to take over the environment of the gut eventually producing a stable state of intestinal health, creating an environment for more complete digestion, absorption and assimilation of nutrients. The mechanisms by which the microflora can contribute to intestinal health of poultry include growth promotion, improvement of the mucosal architecture, degradation of non-fermentable substrates into digestible components, improvement of intestinal and general health, breakdown of cytotoxic substances, production of vitamins, suppression of pathogens, competition for nutrients, competition for adhesion sites at the mucosal epithelium, stimulation of intestinal motility, stimulation of the immune system, production of volatile fatty acids and production of antimicrobial substances.

Generally, probiotic preparations are used on farms as soon as chicks arrive. The most common routes of administrating probiotic preparations are via feed and drinking water (Khan *et al.*, 2011a; 2011b), but less common methods include *in ovo* injection (Edens *et al.*, 1997), the use of sprays (Blankenship *et al.*, 1993), oral dosing and more recently the 'vent lip' method (Higgins *et al.*, 2008).

This paper briefly describes the beneficial effects of probiotics on poultry production systems and summarises what is currently understood about their colonisation in the gastrointestinal tract, their metabolism and their mechanisms of action in altering host animal health and performance. From this information, a paradigm can be proposed that might be of use in future poultry probiotic studies that will facilitate integration of the findings of one study with another.

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Probiotic selection, isolation and methodology development

The isolation and characterisation of probiotic bacteria is of special interest in terms of the criteria used for strain selection, physiological characteristics, tolerance to conditions in the digestive tract, multiplication and operating capacity in the intestine, the effect on the immune system, antibacterial factors, the ability to colonise, resistance to industrial processing, their efficacy and safety. All bacteria used as probiotics are now selected on the basis of these criteria in particular *Lactobacillus* and *Bifidobacterium*.

Despite the difficulties of applying the results obtained by *in vitro* methods to the *in vivo* situation, the initial screening of strains remains a first step in detecting probiotic candidates. Different strains display distinct features, some of them showing strong antagonistic activities, others having advantageous technological features (*e.g.* ease of production or resistance to thermal processing), and others, in turn, score well in safety aspects (*e.g.* antibiotic susceptibility patterns). Therefore, it is more likely that beneficial effects in the complex environment of the gut will require the introduction of a mixture of strains. *In vitro* screening techniques for probiotic candidates that have pathogen exclusion capabilities have been well documented. For example, Bielke *et al.* (2003) described an *in vitro* screening method for probiotic candidates that resulted in a defined culture of 24 selected isolates that were effective against *Salmonella* in young poults. Screening for multiple positive traits of probiotic candidates has also been documented. For example, in the European Union C-EX project, a variety of intestinal bacteria (with special focus on lactic acid bacteria and bifidobacteria) were isolated from various chicken GIT sources and were assayed for antimicrobial activity, adherence properties, fermentation characteristics, and antibiotic susceptibility patterns (Klose *et al.*, 2006). Out of 121 well-characterised strains, a reduced number of 90 stains exhibited the ability to inhibit a pathogenic indicator strain of *S. enterica* serovar *enteritidis*. Antagonism to a series of pathogenic strains affiliated with *S. enterica* serovar *choleraesuis*, *E. coli* serotypes O157:H7 and O147:H19, *Campylobacter jejuni*, and *C. perfringens* were shown in 20 strains. As indicated by both Giemsa staining and agar plating assays, the ability to adhere to the Caco-2 cells varied considerably among the test strains and was found to be highly strain specific. Five effective strains (*P. acidilactici*, *E. faecium*, *Bifidobacterium animalis* ssp. *animalis*, *Lactobacillus reuteri*, and *Lactobacillus salivarius* ssp.) were found to perform consistently well against a broad range of common poultry pathogens and were evaluated with regard to further selection criteria, including growth and fermentation performance, pH reduction, and biosafety (*e.g.* lack of virulence determinants, antibiotic susceptibility, and lack of plasmid-linked resistance to clinically relevant antibiotics) (Klose *et al.*, 2006).

Genetic stability is required in probiotics and an isolated specified target of the functional strain needs to be identified. Lactic acid producing bacteria (LAB) belonging to the genus *Lactobacillus* have been isolated from a variety of habitats, including plant and dairy products, meat products, sewage and manure, and humans and animals. Several isolates from animal hosts including chickens were found to be acid and bile tolerant (Fujisawa *et al.*, 1992; Gusils *et al.*, 1999). Although several *Lactobacillus* spp. have been isolated from chicken faeces, most of the strains isolated so far have been mesophiles. However, the isolation of *Lactobacillus* spp. from chicken faeces under high temperatures has been studied (Niamsup *et al.*, 2003). Traditional cultivation and microscopy have been improved by the introduction of genotypic studies. The latest techniques involve analysis of ribosomal RNA, specifically to the subunits 16S and 32S rRNA for bacteria (Wilson and Blitchington, 1996). The use of polymerase chain reaction (PCR) assay methods with 16S rRNA analysis has been studied in the identification of organisms isolated from chicken hosts, human faeces

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and animal feed (Likotrafiti *et al.*, 2004). A new, real-time quantitative PCR with 16S rRNA gene-targeted species/group-specific primers has recently been introduced to analyse LAB in the intestines and faeces of humans (Gueimonde *et al.*, 2004). A real-time PCR assay for rapid and sensitive detection of a novel thermotolerant bacterium, *Lactobacillus thermotolerans*, in chicken faeces was developed and assessed by Selim *et al.* (2005). Whole-cell protein profiling method by SDS PAGE is an additional method used to identify a new thermotolerant species of LAB isolated from chicken faeces (Sow *et al.*, 2005), and to identify the isolates from 55 European probiotic products (Temmerman *et al.*, 2002). There are less time-consuming techniques available, such as distortion in gradient electrophoresis (Yang *et al.*, 2009). However, the most efficient method is to use species-specific primers that allow direct identification of probiotic organisms. There are now methods available to investigate the physiological characteristics of probiotics. Of these the most commonly used are fermentation of carbohydrates and enzymatic activity. There are more specific tests, such as the ability to hydrolyse bile salts (Lim *et al.*, 2004) or to produce antimicrobial substances (Toure *et al.*, 2003).

Probiotic colonisation and attachment within the gastrointestinal tract

Microbial colonisation begins after hatch, but the development of the intestinal microflora and the gut barrier is a gradual process. Adhesion and colonisation are important for selection and use of probiotic strains. The GIT in broilers is sterile at hatching, and bacteria from the environment or the diet immediately colonise. After this initial colonisation, other bacterial species have more difficulties in establishing themselves. Under natural conditions, the microflora colonising the GIT a few days after birth consists of 400 to 500 different bacterial strains with a total count of around 1014 bacteria (Busch *et al.*, 2004). The microflora consists of transient bacteria which temporarily reside in the tract, and indigenous bacteria that colonise the intestinal tract permanently. Colonisation by a bacterial species is defined as 'a bacterial population in the GIT which is stable in size and occurrence over time, without the need for periodic reintroduction of bacteria by repeated oral doses or other means' (Snel *et al.*, 2002). In poultry, the crop, proventriculus and gizzard have very low anaerobic bacteria numbers due to the presence of the oxygen consumed with the feed as well as the low luminal pH, primarily associated with the hydrochloric acid within the proventriculus (Rastall, 2004). In poultry, probiotic bacterial colonisation, as measured by colony forming units (CFU), increase in number beginning at the beak and progressing distally to the colon (Simon *et al.*, 2004). Probiotic organisms can be divided into two general groups based on their tolerance to oxygen, anaerobes and facultative anaerobes. The small intestine has large bacterial numbers consisting of facultative anaerobes such as *Lactobacilli*, *Streptococci* and *Enterobacteria* as well as anaerobes such as *Bifidobacterium* spp., *Bacteroides* spp. and *Clostridia* spp. at levels ranging from 10^4 to 10^8 CFU/ml (Gaskins, 2003). The most heavily colonized regions of the GIT are the colon and caecum with colonisation of 10^{10} to 10^{13} CFU/ml (Heczko *et al.*, 2000). Probiotic bacteria colonise three different areas within the GIT, the enterocyte surface, the caecal epithelia surface and the colonic epithelia surfaces (Yamauchi and Snel, 2000). Each of these areas generally includes three microenvironment components. The digesta, the surfaces of the enterocytes and the caecum and colon and the mucous blanket covering the epithelial surface as well as the epithelial cells of the caecum and colon. The digesta, which is created by the consumption of a rich milieu of feed nutrients and water, is an ideal environmental niche within which many bacterial species flourish. Probiotic bacteria can be found attached to individual feed

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particles such as starch granules. Other bacteria are not associated with the feed particles, but simply exist within the aqueous matrix of the digesta. The second microenvironment of the GIT where microbes are found is within the mucous blanket that covers the epithelial lining of the GIT including the intestinal villi, caecal and colonic surfaces. Mucous not only serves as an environment within which these microbes exist, but also serves as a source of nutrients for bacteria (Jacobsen *et al.*, 1999). Finally, bacteria can be associated with or attached to the surface of the apical plasmalemma of the epithelial cells lining these areas. However, the functional relationship of bacteria associated with the three GI micro environments described above and its biological significance has not been established (Kankaanpaa *et al.,* 2004). The ability of many strains of probiotic bacteria to physically adhere to portions of the GI micro environments may speak to their ability to effect changes in enteric health (Sarem-Damerdji *et al.*, 1995). Attachment to the enterocyte's plasmalemma is considered the first step in the colonisation of the host enterocyte surfaces. This permits probiotic organisms to resist both peristalsis and/or mixing with the digesta and mucus layer and subsequent removal from the gut. However, adherent probiotic bacteria usually do not colonise the intestinal epithelium permanently and are normally eliminated from the GIT a few days after cessation of supplementation (Gusils *et al.*, 1999). The ability of a probiotic strain to adhere to mucus and epithelial cell surfaces is one of the main selection criteria for a candidate probiotic (Rojas and Conway, 1996). Very few studies have investigated adhesion and colonisation of probiotic bacteria because of the complexity of the intestinal enterocytes and the extensive interaction amongst intestinal cell types within the intestinal tract (Henriksson *et al.*, 1991). Successful probiotic colonisation depends on the survival and stability of the probiotic strain, specificity of the strain relative to host, dose and frequency of administration, health and nutritional status of the host, effect of age, stress and genetics of the host (Mason *et al.*, 2005).

Scanning electron microscope (SEM) has been introduced to study the density and survival of probiotics in the chicken intestine after feeding such supplements (Thanaruttikannont and Rengpipat, 1995). Different methods are used to study bacterial adhesion to intestinal epithelial cells, which is an important step in pathogenic infection as well as in probiotic colonisation of the intestinal tract. Le Blay *et al.* (2004) conducted comparative detection of bacterial adhesion to Caco-2 cells with ELISA, radioactivity and plate count methods. The methods tested gave similar results for the highest bacterial concentrations. However, differences among methods increased with the addition of decreased bacterial concentration due to different detection thresholds. The ELISA-based method was shown to be a good predictor for bacterial adhesion compared to the radio labelling method when good quality specific antibodies were used. This technique is convenient and allows simultaneous handling of numerous samples. Fluorescent staining of *Lactobacillus* and *Bifidobacterium* strains and a *Bifidobacterium* mixture using the viable probe carboxyfluorescein diacetate has been attempted (Bianchi *et al.*, 2004). These cells were incubated on Caco-2 mono layers and subsequent spectrofluorimetric detection following the lysis of the attached bacterial cells was done. The results were expressed as adhesion percentages, and proved that fluorescent labelling is suitable for adhesion studies and provides a reliable and safer alternative to radioactive labelling.

Nutrient metabolism of common probiotic bacteria

The facultative anaerobe genera, *Bifidobacterium* and *Lactobacillus* reduce the redox potential in the gut and render the environment suitable for obligate anaerobes. Anaerobic

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fermentation of carbohydrates and proteins yield metabolic intermediates such as lactate, succinate, short chain volatile fatty acids (VFA), H_2CO_2, CH_4 and a bacterial biomass that acts as an electron acceptor via substrate level phosphorylation (Macfarlane and Cummings, 1999). Most of the VFA formed by intestinal bacteria are absorbed and metabolised by the bird, contributing to the host's energy requirements (Fooks and Gibson, 2002). Some bacterial metabolites, like ammonia, phenols and amines, resulting from the breakdown and fermentation of proteins, are toxic (Dommett *et al.*, 2005). *Lactobacilli* are involved in both homolactic and heterolactic fermentation. Homolactic fermentation involves splitting of hexoses into C_3 moieties using fructose-1, 6-bisphosphate via the glycolytic pathway. This process yields two pyruvate molecules which are then converted into lactate. Two moles of ATP are generated per mole of glucose from this type of fermentation. Heterolactic fermentation proceeds via the pentose phosphate pathway, to produce lactate, CO_2 and ethanol, generating one mole of ATP per mole of glucose. Phosphoketolase is the key enzyme involved in this process (Chichlowski *et al.*, 2007).

Bifidobacteria make a significant contribution to fermentation in the colon. *Bifidobacteria* ferment carbohydrates to fructose-6-phosphate, via fructose-6-phosphate phosphoketolase (Marteau, 2000). The principal end products of fermentation by *Bifidobacteria* are acetate and lactate which are produced in a 3:2 molar ratio (Gill *et al.*, 2001). Additionally, *Bifidobacteria* produce a wide-range of antimicrobial agents that are effective against both gram-positive and gram-negative organisms. These agents might include antimicrobial peptides, such as defensins, cathelicidins and lysozyme (Fooks and Gibson, 2002). *Bifidobacteria* have been reported to alter faecal bacterial enzyme activities, reduce antibiotic-induced side-effects, inhibit mammary and liver tumours and, in conjunction with oligofructose, reduce 1, 2-dimethylhydrazine-induced colonic carcinogenesis in mice (Marteau *et al.*, 2004). Oral supplementation of *Bifidobacterium lactis* in elderly human subjects increased the production of total, helper $CD4^+$ and activated $CD25^+$ T lymphocytes and natural killer cells (NK); and increase the phagocytic activity of mononuclear and polymorphonuclear phagocytes and the tumoricidal activity of NK (Chichlowski *et al.*, 2007).

Intestinal nutrient transport

The effects of probiotics include increases in the specific and total activities of the brush-border membrane enzymes in the jejunal enterocytes of growing rats. After oral treatment of rats with *S. boulardii*, there was a marked stimulation of sodium dependent D-glucose uptake into brush border membrane vesicles with a corresponding increase of the sodium D-glucose cotransporter-1, SGLT-1 (Eberl, 2005). It has also been reported that the oral administration of *L. casei* increased the crypt cell production rates of the jejunum, ileum, caecum and distal colon in rats (Kohler *et al.*, 2003). Additionally, Chichlowski and co-workers have reported that a probiotic consortium increases passive absorption of glucose in the chicken ileum (Chichlowski *et al.*, 2006).

Inhibition of pathogenic bacteria

The gastrointestinal environment contains a wide range of contents ranging from harmless beneficial dietary and microbial flora to harmful pathogenic bacteria. The host organism fights against these pathogenic bacteria through various means,

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including blocking pathogenic bacteria effects by producing bactericidal substances and competing with pathogens and toxins for adherence to the intestinal epithelium, regulation of the immune responses by enhancing the innate immunity and modulating pathogen-induced inflammation via toll-like receptor-regulated signalling pathways, regulation of intestinal epithelial homeostasis by promoting intestinal epithelial cell survival, enhancing barrier function and stimulating protective responses. This strategy is based on the ability of probiotic bacteria to bind pathogens in intestinal epithelial tissue. The anti-pathogenic action of probiotics consists of the production of lactic acid which decreases the pH, interaction with the toxins produced by pathogens, with the production of hydrogen peroxide and the synthesis of bacteriocine (Corcionivoschi and Drinceanu, 2009).

Probiotic bacteria can prevent the colonisation by potentially pathogenic bacteria by the enhancement of intestinal barrier function through modulation of the cytoskeleton and epithelial tight junctions in the intestinal mucosa (Ng *et al.*, 2009). Such enhancement of epithelial integrity is accomplished by two mechanisms (Chichlowski *et al.*, 2007). First, the enterocytes produce a thick blanket of mucus, secreted by goblet cells which are dispersed throughout the luminal epithelium of the intestines. In one experiment, treatment with probiotic bacteria triggered an increase of 60% of basal luminal mucin contents by up-regulation of *MUC2* gene expression (Caballero-Franco *et al.*, 2007). In the same experiment, an increase in the number of goblet cells in chicken intestinal villi in response to probiotics suggested that metabolites produced during bacterial fermentation may play a role in the growth and maturation of goblet cells. The second mechanism that ensures epithelial barrier integrity is associated with a unique structure called a 'tight junction'. This is an unbroken, contiguous biological barrier which prevents the entrance of macromolecules and pathogenic bacteria. Tight junction proteins are dynamic structures subject to changes that dictate their function.

The effect of probiotics on the cytoskeleton of tight junctions came to light when intact epithelial cell junctions were investigated using electron microscopy (Shen *et al.*, 2006). Tight junction permeability is influenced by the hormone zonulin, which is involved in the movement of molecules from intestine into the blood stream and vice versa (Shen *et al.*, 2006). The protective action of zonulin was reported in response to the administration of non-steroidal anti-inflammatory drugs when the animals were dosed with *Lactobacillus* (Buts *et al.*, 2002). However this mechanism is till vague and not fully understood. The cytoskeleton arrangement was restored under the treatment of probiotic (VSL# 3), suggesting a role of probiotics in preservation of barrier function and cytoskeleton architecture (Ng *et al.*, 2009). Similarly, other probiotic bacteria such as *L. acidophilus*, *S. thermophilus*, individually or collectively, maintain or stabilise other cytoskeleton structures like actin, ZO-1 and occluding when disrupted by pathogenic bacteria (Ng *et al.*, 2009).

Some bacteria have been shown to have antioxidative properties, such as *Bifadobacterium longum* and *L. acidophilus*. These bacteria have been demonstrated to scavenge the α,α-diphenyl-β-picrylhydrazyl (DPPH) radical which lead to the inhibition of lipid peroxidation and reduction of DNA oxidative damage in intestinal epithelial cells (Lin and Chang, 2000).

Probiotic bacteria are known to produce a class of small, antimicrobial molecules that are collectively known as bacteriocins (Kohler *et al.*, 2002). Bacteriocins can kill pathogenic bacteria or impede their colonisation (Bar-Shira and Friedman, 2006). They are comprised of proteins or protein complexes which can have antagonistic activity against species related to the producer bacterium. Additionally, other non-bacteriocin compounds are produced by probiotics which inhibit the growth of pathogens (Madsen *et al.*, 2001). The polyamine derivate piperidine, which is

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produced by intestinal microflora as the result of amino acid degradation, has been shown to inhibit the binding and internalisation of *Salmonella* and *Shigella* to intestinal epithelial cells *in vitro* (Gusils *et al.*, 2003).

Lactic acid bacteria generally produce a variety of factors such as bacteriocins, antibiotics, lactic acid and peroxides. These substances help the colonisation of intestinal mucosa by probiotic bacteria by preventing the attachment of pathogens, and hence competition for attachment sites. In broilers, bacteria of the genus *Enterococcus* produces bacteriocin substances which have an inhibitory effect on pathogenic *Clostridium* and *Listeria* spp. (Shin *et al.,* 2008). *Lactobacilli* and *Bacillus cereus* have been reported to produce various types of antibiotics (Risøen *et al.*, 2004). *Lactobacillus acidophilus* produces acidophilin, lactocidin, and acidolin, and *L. plantarum* produces lactolin. Among the anti-metabolites, nisin and diplococcin are produced by streptococci. *Bacillus cereus* produces bacteriocin-like substances that inhibit closely related *Bacillus* spp. and others such as *Staphylococcus aureus* and *Micrococcus luteus* with activity in the pH range of 2.0-9.0 (Risøen *et al.*, 2004). Acidophilin, acidolin, lactobacillin, and lactocidin have been shown to exert *in-vitro* inhibitory activity against *Bacillus*, *Klebsiella*, *Pseudomonas*, *Proteus*, *Salmonella*, *Shigella*, *Staphylococcus*, *Vibrio* spp. and enteropathogenic *E. coli*.

As probiotic micro-organisms are not deemed an alternative to treatment for acute diseases, they should not be considered a curative medicine against any specific disorder. Probiotic micro-organisms should only be used to aid feed conversion and prophylactically against sub-clinical disorders. In the factual sense they are not growth promotants, but rather growth permitants, allowing the host to best express its genetic potential.

Conclusions

The concept of probiotics now comprises an important aspect of applied biotechnological research and, as opposed to antibiotics and chemotherapeutic agents, can be employed for growth promotion in poultry. In past years, it was common to consider all bacteria as harmful, ignoring the use of the organisms in food preparation and preservation, thus making the probiotic concept somewhat difficult to accept. Scientists now are now better understanding the delicate symbiotic relationship of poultry with their gut bacteria, especially in the digestive tract, where they are very important to the well-being of poultry. Since probiotics do not result in the development and spread of microbial resistance, they offer immense potential to become an alternative to antibiotics. The current literature reveals that probiotics may be successfully used as nutritional tools in poultry feeds for promotion of growth, modulation of intestinal microflora and pathogen inhibition. However, more research is needed to fully define the mechanisms of probiotic effects on the body before they can be employed by the industry in a consistently efficacious manner.

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