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POLICY ARTICLE

Nutrition and gut health: scope for sustainable animal production

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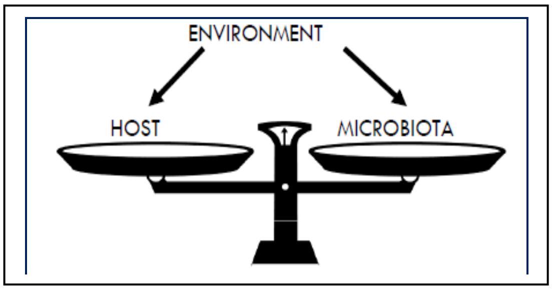
Agriculture including the livestock as an integral component plays an important role in Indian economy (DAHD&F, MOA, GOI, 2020). Livestock is considered a major source of income for the poor masses in developing countries including India, where it contributes, nearly 4.11 percent to total GDP & 25.6% of total Agriculture GDP. (DAHD, 2020; Delgado *et al*., 2020). Health of gastrointestinal tract and its effective functioning is an important factor in determining animal performance (growth, milk yield, meat and egg quality) (Celi *et al*., 2017).

GUT HEALTH:

Defined as the "absence of clinical diseases" in human medicine (Bischoff *et al.,* 2011). A new definition of gastrointestinal functionality has been recently presented. The proposed definition of gastrointestinal functionality (a steady state where the microbiome and the intestinal tract exist in symbiotic equilibrium and where the welfare and performance of the animal is not constrained by intestinal dysfunction), integrates the principal components of gastrointestinal functionality, namely diet, intestinal permeability and gut microbiota, with digestion and absorption of feed and effective immune status. All these domains play a critical role in gastrointestinal physiology, animal health, welfare and performance (Celi *et al.,* 2017).



Component of gut health:

Conway (1994) proposed three components of gut health namely the diet, the mucosa, and the commensal flora. Recently six major domains related to gastrointestinal functionality have been proposed. These domains include diet, effective digestion and absorption, normal and stable microbiota, effective immune status, gut mucosa, and neuroendocrine and motor function of the gut (Celi *et al.,* 2017).

A healthy gut is a gut in which the environment is regulated as such that a stable and constant condition is maintained. This is called homeostasis.

At birth, the digestive tract of neonates is devoid of microorganisms. Immediately after birth however, as soon as the animal is exposed to the environment, a versatile microflora begins to develop. Consequently, the gut is colonized by a large number of microorganisms, most of which are harmless while others may be pathogenic. The gut microflora, both in terms of total numbers and composition, differs greatly between animal species and different gut sections.

Total number of micro-organisms present in the stomach and proximal small intestine of non-ruminants (pigs, poultry) is relatively small (10'-10^5 colony-forming units per gram of digesta), most of them being aerobe and facultative anaerobe bacteria such as *Lactobacilli, Streptococci* and *Bacteroides.* From the proximal to the distal part of the gastrointestinal tract, the number of microorganisms increases considerably. In the terminal ileum, population density ranges between 10^8 and 10^9 CFU/g of gut content. Thereafter, due to a longer residence time of the digesta, the number of microorganisms increases dramatically (10^{10} -10^{12} CFU/g digesta) in the large intestine, the predominant species being strictly anaerobe. The microflora may exert a number of effects in the gut, which in turn may positively or negatively impact the health status of the host animal.

According to Richards *et al.* (2005), these effects can be summarized as follows:

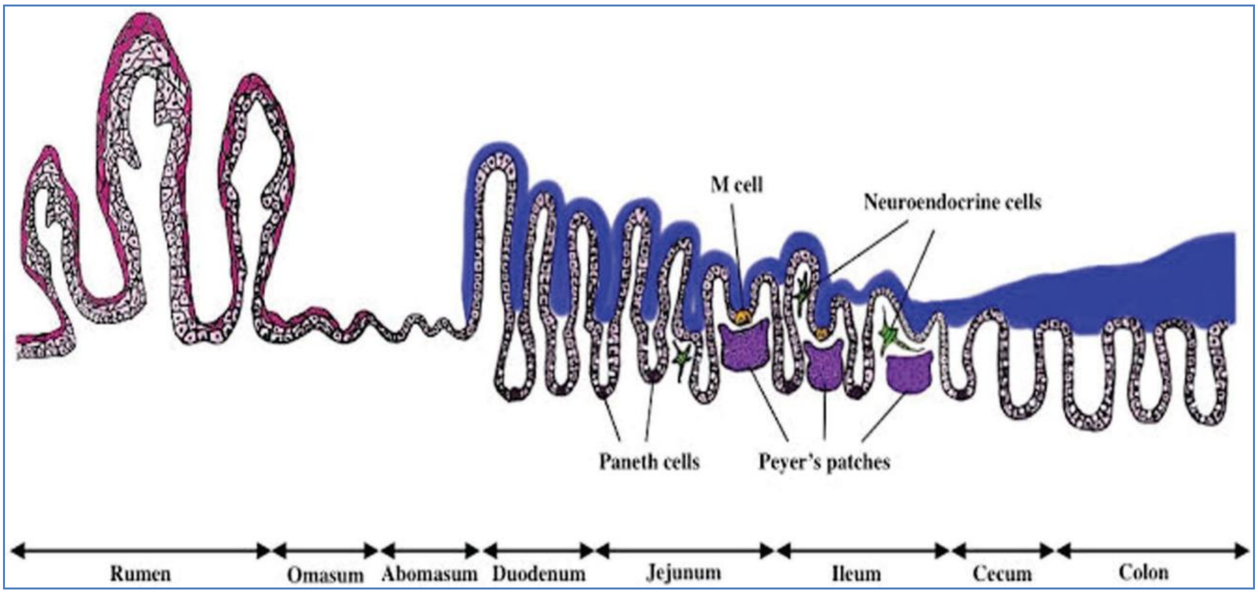
- Production of lactic acid and fatty acids (acetate, propionate, butyrate).
- Lowering of pH, Secretion of antimicrobial compounds (bacteriocins), Competition with the host and other microorganisms for nutrients.
- Competition with other microorganisms for attachment sites at the gut surface, Stimulation of host immunity
- Stimulation of cell turnover, Increased mucus production, Modification of intestinal morphology (villus height, crypt depth), Decreased fat digestibility, Increased energy requirement of the host.

Development and physiology of the rumen and the lower gut: Targets for improving gut health:

The primary roles of the gastrointestinal epithelium are to protect the host from the mixture of microorganisms, toxins, and chemicals in the lumen and to prevent unregulated movement of these compounds into the lymphatic or portal circulation (Gabel *et al.,* 2002).

COMPARATIVE STRUCTURE OF EPITHELIA:

The contents of the gastrointestinal lumen are separated from the lymphatic and portal circulation by 2 distinct epithelia: the stratified squamous epithelium (**SSE**) found in the reticulo-rumen and omasum and the columnar epithelium (**CE**) of the abomasum, small intestine, cecum, and large intestine, otherwise known as the lower gut.



The diverse epithelial structure (Stratified squamous epithelium and columnar epithelium), cell types (Paneth, M, and neuroendocrine cells) and mucus layer (blue) of healthy GIT of ruminants. **(Steele *et al.,* 2016)**

In the reticulo-rumen and omasum, the SSE epithelial surface area is increased by papillae that protrude from the ruminal epithelium to increase absorption of short chain fatty acids (**SCFA**) and minerals and secretion of bicarbonate into the lumen (Aschenbach *et al.,* 2011). Similar to the SSE, the CE cells are joined by tight junctions, adherent junctions, and desmosomes (Turner, 2009).

The characteristics of the lower gut are different from those of the reticulo-rumen and omasum for several reasons. First, instead of multilayered SSE, there is a simple CE in the lower gut. The cells of the lower gut encompass absorptive epithelial cells, mucus-secreting cells (goblet cells), immune cells (Peyer's patches, Paneth cells, dendritic cells, and lymphocytes), and enteroendocrine cells. These specialized cells carry out essential processes; for example, they secrete protective substances (e.g., mucus, antimicrobial peptides) into the lumen, secrete enzymes into the lumen, facilitate nutrient absorption, and secrete hormones [e.g., peptide YY, glucagon-like peptide (**GLP**)-1, and GLP-2]. The ileum is richest in immune cells, whereas the duodenum and colon are richer in mucous cells. Additionally, the reticulo-rumen and omasum SSE are not mucosae, whereas the entire lower gut comprises loosely adherent and firmly adherent mucus layers that act as an intermediate between the lumen contents of the lower gut and the epithelial cells. Mucus layers are predominantly composed of mucin networks (*MUC2* produced by goblet cells) and other host-defense molecules produced by goblet cells, Paneth cells, and absorptive enterocytes. The mucus layer is thinnest in the duodenum and thickest in the colon. The submucosa is structurally diverse depending on the region of the lower gut. For example, Brunner's glands or mucus pits line the duodenum, and Peyer's patches, which play an important role in immunological function, line the ileum.

Gastrointestinal tract of Horse:

Within their enteral tract, horses are able to host up to 10^{15} bacterial cells with the majority of bacteria residing in the colon, especially within the comparatively enlarged caecum (Cunha, 1991). Degradation of non-digestible cellulosic and hemi-cellulosic forage components by these microorganisms is crucial for the bioavailability of energy and other essential nutritional needs in horses. (Blackmore *et al.,* 2013; Julliand & Grimm, 2016)

Gastrointestinal tract of Chicken:

The gastrointestinal tract of poultry, the most extensive body surface exposed to environmental influence, is the home of complex and highly diversified molecularly defined microbiota, containing an enormous number of different species that can be called the microbial community or microbiome. Composition and density of microbiota depend on the microbial composition of the inoculum introduced at hatch, first diet, and host intestinal epithelium. The initial bacteria grow very fast, and the sterile environment soon becomes inhabited by 10^8 and 10^{10} bacteria per gram of digesta in ileum and cecum, respectively in day 1–3. The bacterial density reached a maximum in a different section of GIT within the first week of age.

The GIT harbors more than 100 billion bacteria. In a healthy balanced microbial community, there are mostly beneficial gram-positive bacteria (at least 85% of total bacteria), and remaining bacteria includes *Clostridium* in young birds and *Salmonella, Campylobacter*, and *E. coli* in older birds without any intestinal disturbance. Some of the commonly found microbes in the GIT of poultry are *Lactobacillus sp., Bacteroides sp., Eubacterium sp., Clostridium sp., Escherichia coli, Streptococcus sp., Prevotella sp., Fusobacterium sp., Selenomonas sp., Megasphaera sp., and Bifidobacterium sp.*

EUBIOSIS AND DYSBIOSIS:

The eubiosis called the balance of the healthy gut living man many microorganisms. Together they protect against pathogenic germs and help with digestion. Inhibition of growth of harmful bacteria, more symbionts condition in gut._Dysbiosis (also called dysbacteriosis) is characterized as a disruption to the gut microbiota homeostasis caused by an imbalance in the microflora, changes in their functional composition and metabolic activities, or a shift in their local distribution. It is a term for a microbial imbalance or maladaptation on or inside the body, such as an impaired microbiota. (Iebba *et al*., 2009)

The intestinal microbial ecosystem balance, called eubiosis, is a fundamental concept. As early as 400 B.C. Hippocrates said “death is in the bowels” and “poor digestion is the origin of all evil”. Ali Metchnikoff, who lived from 1845 to 1916, suggested that most disease begins in the digestive tract when the “good” bacteria are no longer able to control the “bad” ones. He called this condition dysbiosis, meaning an ecosystem where bacteria no longer live together in mutual harmony. A gut microbiota in a eubiotic *status* is characterized by a preponderance of potentially beneficial species, belonging mainly to the two bacterial phylum *Firmicutes and Bacteroides*, while potentially pathogenic species, such as that belonging to the phyla *Proteobacteria (Enterobacteriaceae)* are present, but in a very low percentage. In case of dysbiosis "good bacteria" no longer control the "bad bacteria" which take over.

Beneficial roles of gut microbiota:

- Provides nutritional compounds to the host in the form of fermentation end-products and other secreted products such as SCFAs, specialized enzymes, amino acids, B and K vitamins and absorption of ions. (Snel *et al.,* 2002; Oakley, 2014)
- Commensal bacteria generate SCFAs such as acetate, propionate, butyrate, and lactate in the GIT of chicken. These SCFAs have their specific role in the GIT such as contribution to energy by gluconeogenesis and also stimulate gut epithelial cell proliferation, differentiation and increases the villus height, thereby increasing the absorptive surface area. (Vadder *et al.,* 2014). Reducing undesirable bacterial species in the cecum.

Harmful roles:

- Commensal bacteria compete for nutrition with the host and produce toxic compounds as a byproduct of metabolism.
- Undigested protein of feed origin, true endogenous protein (mucin, epithelial cells, enzymes, and antibodies) and microbial proteins which bypass the small intestine and are available for the microbiota in the large intestine.
- These microbiota ferment bypass proteins to produce toxic metabolites such as ammonia, amines, phenols, cresol and indoles which can impact intestinal cell turnover and even growth performance.
- **POSSIBLE APPROACHES TO MAINTAIN THE GUT HEALTH.**

Probiotics	*Lactobacillus acidophilus*, *Bacillus spp.*, *Enterococci faecium*
Prebiotic	Mannan oligosaccharide, Fructo oligosaccharide, Galacto oligosacchride
Herbs and plant extracts	Ex: Phytogenic feed additive
Synbiotic	Combination of Prebiotics and Probiotics
Organic acids	Ex: Formic acid, Lactic acid,
Antibiotics and Miscellaneous	Zinc Bacitracin

1. PROBIOTICS:

Probiotics are products consisting of live microorganisms which beneficially influence the host by improving the intestinal microbial balance (Fuller, 1989).These include BACTERIA: *Bacillus, Bifidobacterium, Enterococcus, Lactobacillus, Streptococcus, and Lactococcus spp.)*,YEAST – *Saccharomyces sp*. According to Traldi *et al*. (2007), probiotics can improve the utilization of food and thereby reduce nutrient excretion. Furthermore, there is a tendency to increase the use of probiotics in diets for animals, which is a more reasonable option, since they do not leave residues in the environment, in the animal body and do not cause cross-resistance in men compared with antibiotics.

Properties of Probiotics: Since the beneficial effects of probiotics are based on modification of the gut microflora, it is a prerequisite that the micro organisms reach the gut in viable form and are live during feed processing, storage and passage through the highly acidic stomach. Preparations authorized for use in animal nutrition in the European Union include different strains of *Enterococcus, Bacillus, Lactobacillus or Saccharomyces.*

Mode of action: Mainly based on three principles: Competitive exclusion, Bacterial antagonism, Immune modulation.

2. Prebiotics:

Prebiotics are non-digestible feed ingredients that are responsible for altering the composition and metabolism of gut microbiota selectively (Huyghebaert *et al.,* 2011). Prebiotics has the ability to increase the number of bifidobacteria and other species that affect the health of host positively. Commonly used prebiotics are oligosaccharides including inulin, fructooligosaccharides (FOS), mannanoligosaccharides(MOS), galactooligosaccharides, soya-oligxosaccharides, xylo oligosaccharides, pyrodextrins, and lactulose.

Mode of action:

Microbial degradation of prebiotic carbohydrates results in accumulation of short-chain fatty acids (mainly acetate, propionate and butyrate) and coincides with a lowering of the gut pH, particularly in the large intestine. Chickens lack enzymes required to degrade the glycoside link between xylose units, therefore XOS is available for fermentation in the distal intestine by xylanolytic bacteria. The composition of the intestinal microbiota in broilers could be shifted by fermenting XOS towards a relative increase in probiotics and a decrease in pathogenic bacteria. Additionally, fermentation of XOS in the cecum of broilers leads to formation of short-chain fatty acids (SCFA) which was implicated in energy absorption, alleviation of gut inflammation, and maintenance of intestinal epithelial integrity.

3: Synbiotic: Both probiotics and prebiotics have been shown to provide beneficial effects on the gut of birds. When probiotics and prebiotics are combined, they form synbiotics. This combination could improve the survival and persistence of the health-promoting organism in the gut of birds because its specific substrate is available for fermentation. Jerusalem artichoke is a good source of prebiotics, specifically a source of fructooligosaccharide (FOS).

4: Phytogenic feed additives:

Phytogenics are a group of natural growth promoters (NGPs) or non-antibiotic growth promoters used as feed additives, derived from herbs, spices or other plants. Phytogenic feed additives (PFA), are incorporated into animal feed to enhance productivity through the improvement of digestibility, nutrient absorption and elimination of pathogen residents in the animal gut. Digestive stimulation by phytogenic additives is achieved through stimulation of saliva secretion, liver, pancreas and intestine enzymes activities, intestine function and morpho-histology and metabolism. These products of plant origin are natural, less toxic, residue free and ideal feed additives for animal when compared to synthetic antibiotics or inorganic chemicals. Phytogenic substances have antimicrobial, antifungal, antiparasitic antiviral, antitoxigenic and insecticidal properties. Phytogenic feed additives are either available in a solid, dried and ground form or as extracts or essential oils.

Effects on intestinal health:

Intestinal health is a prerequisite for optimal performance and profitability in animal fattening and egg production (poultry) with optimized feeding strategies playing a central role. Intestinal disorders usually cause a damage of the intestinal mucosa. The body's reaction includes an accelerated renewal of the damaged tissues. This process is complex and requires additional energy.

5: Essential oils and organic acids:

Essential oils: EOs (also referred as volatile or ether oils) are complex mixtures of volatile lipophilic secondary metabolites. They are typically extracted from plant material by boiling water and steam distillation, but other methods also include solvent extraction, supercritical CO2 extraction, and expression extraction. Chemically, EOs are typically composed of phenylpropene and terpene secondary metabolites. Essential oils contain many different compounds with antimicrobial activity, such as hydrocarbons, phenols, ketones, esters, and ethers.

Thymol: Thymol is a monoterpene [5-methyl-2-(1-methylethyl) phenol; C10H14O] with strong antimicrobial activity against a wide range of gram-positive and negative bacteria, and is one of the well-researched active components of Eos.

Organic acids, for instance, propionate and medium-chain fatty acids, which have growth promoting properties and antimicrobial activities, have shown a greater capacity as an alternative to antibiotics. Organic acids have been shown to decrease mortality in experimentally infected chickens through reducing the concentrations of Escherichia *coli,* Salmonella *spp.* and coliform in the small intestine.

CONCLUSION:

Sound gut health as achieved by feeding of prebiotic, probiotic synbiotic , phytogenic feed additives, organic acids and essential oils in animals. As the feeding of probiotic, prebiotic, synbiotic increases the villi length , improved a higher villus height-to-crypt depth ratio of the duodenum, jejunum, ileum and increases the surface area as a result better nutrient absorption which intern leads to enhanced productivity, efficiency and profitability support sustainable animal production.

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