Artykuł przeglądowy *Review*

Is a holistic approach to the treatment of enteropathy in poultry justified?

ANDRZEJ KONCICKI, BARTŁOMIEJ TYKAŁOWSKI, TOMASZ STENZEL

Department of Poultry Diseases, Faculty of Veterinary Medicine, University of Warmia and Mazury in Olsztyn, Oczapowskiego 13, 10-719 Olsztyn, Poland

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Koncicki A., Tykałowski B., Stenzel T.

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Summary

The aim of this article was to evaluate the rationale behind a holistic approach to the prevention and treatment of gastrointestinal disorders in poultry. The avian digestive tract is functionally integrated with other body systems. This complex system is responsible for feed digestion, nutrient absorption, and excretion of undigested waste products. Therefore, it plays a crucial role in overall health and welfare, and dysfunctions affecting any part of the gastrointestinal tract can have serious consequences. In view of the anatomical structure of the avian digestive tract and the specificity of nutrient uptake, absorption, digestion, and metabolism, including physiological mechanisms that regulate these processes, a holistic approach is needed to restore homeostasis not only in the gastrointestinal system, but also in the entire organism. The stability of gastric pH and the gut microbiota play a key role in the physiology of the avian gastrointestinal tract. The gut microbiome is composed of diverse collection of microorganisms that exert a crucial influence on the development of the digestive system, its biochemical and immunological functions, and various aspects of animal welfare not limited to nutrient digestion and absorption. The gut-brain axis is a bidirectional communication network between the gastrointestinal tract and the central nervous system that regulates various physiological processes, including immune and behavioral functions. The gut microbiota also affects the activity of the gut-brain axis through neurotransmitters, metabolites, and signalling molecules. Dysfunctions of the gut-brain axis are directly implicated in the pathogenesis of gastrointestinal and neurological disorders in poultry, and they affect the behavior, stress responses, and overall health status of birds. The complex functional interactions between the digestive tract and other body systems and organs, including the gut-brain axis, suggest that the treatment of enteropathy in poultry requires a holistic approach.

Keywords: poultry, enteropathies, holistic approach therapy

In poultry, the gastrointestinal tract is functionally integrated with other body systems. This complex system is responsible for food digestion, nutrient absorption, and excretion of undigested waste products. Therefore, it plays a crucial role in overall health and welfare, and dysfunctions affecting any part of the gastrointestinal tract can have serious consequences. In view of the anatomical structure of the digestive tract in poultry and the specificity of nutrient uptake, absorption, digestion, and metabolism, including physiological mechanisms that regulate these processes, a holistic approach is needed to restore homeostasis not only in the gastrointestinal system, but also in the entire organism. The aim of this article was to evaluate the validity of a holistic approach to the prevention and treatment of gastrointestinal disorders in poultry. This approach is key to reducing antibiotic use in poultry production.

Gastrointestinal health supports nutrient absorption, effective metabolism, and welfare of birds, and it determines productivity in commercial poultry farms. For many years, poultry species have been bred selectively for desirable traits, and new breeding types and lines with high body weight (BW) and high carcass dressing percentage have been developed. Various species of domesticated birds are also selected for faster growth and development of the gastrointestinal tract relative to their wild counterparts. One-day-old slaughter turkey poults raised for meat have much higher intestinal weight than the offspring of wild turkeys, mainly due to differences in intestinal length (18). According to Pinchasov (60), early access to feed is crucial for speeding up the development of the digestive tract in growing birds. Diet also significantly affects the weight and length of the intestines as well as the absorptive surface area of the intestinal mucosa (4, 44, 63, 69). In young birds, the development of the digestive tract can be accelerated through the administration of mannan-oligosaccharides (MOS), which promote the growth of intestinal villi, increase the depth of intestinal crypts, and exert immunostimulatory effects (40, 73). These efforts have contributed to considerable progress in producing efficiency, including in turkeys, in recent decades. In 1960, the BW of turkeys increased by 11 kg over a period of 196 days (28 weeks) with a feed conversion ratio (FCR, kg feed/kg BW) of 4.2, whereas by 2015, the same BW was achieved within only 98 days (14 weeks), and the FCR decreased to 2.13. The FCR continues to decrease each year due to improved conversion of feed nutrients, particularly protein, into BW, especially muscle tissue. In addition to genetic selection for desirable functional traits and the resulting increase in growth rates, improvements in the production technology, nutrition, and biosecurity standards are also required to enhance productivity in poultry farms. An efficient and optimally functioning digestive system is the key determinant of profitability in poultry production. However, genetic selection can compromise bird welfare and health, including digestive health. The first symptoms of digestive disorders include diarrhea, lower weight gains, higher FCR, pododermatitis, and death (39).

A holistic approach to the treatment of enteropathy in poultry requires a thorough knowledge of the morphology and physiology of the avian gastrointestinal system. In the taxonomic hierarchy, birds have been classified between reptiles and mammals, and they share more anatomical features with the former than the latter. The avian digestive system has many unique features that are not encountered in mammals, including the lack of teeth, lips, cheeks, and the soft palate. The oral and esophageal mucosa and the crop are lined with stratified squamous epithelium containing a small number of mucous glands, taste buds that detect the four basic tastes, i.e. sweet, sour, salty, and bitter, as well as water taste receptors (87). The avian esophagus has stretchable walls and forms a crop at the point where it enters the thoracic cavity. The crop is a transitional food store that enables birds to survive periods when the birds are not eating. Dry food is moistened and macerated in the crop. Crop filling does not affect feed intake or satiety, and differences in crop filling are not determined by feed availability (29). Feed intake is regulated by appetite and satiety control centers in the hypothalamus, as well as factors such as the physical form of feed, stimulation of chemoreceptors sensitive to glucose, amino acids, and lipids, stimulation of mechanoreceptors in various segments of the gastrointestinal tract (including the degree of gizzard filling and expansion), the protein and energy content of the feed ration, ambient temperature, access to water, and the health of endocrine and nervous systems (16, 87, 88). During emptying, the crop contracts at 60-90 second intervals, and the frequency of contractions is determined by gizzard filling and the type and consistency of feed in the crop. Soft feed is evacuated from the crop faster than hard components such as cereal grains (29).

The avian stomach consists of the proventriculus (glandular stomach) and the ventriculus (muscular stomach or gizzard). The proventricular mucosa contains glands whose function is similar to that of the mammalian gastric glands, which secrete gastric juices (pepsin, hydrochloric acid). Food remains in the proventriculus for a short period of time, and it passes into the gizzard, where it is ground. The gizzard mucosa contains glands that produce a carbohydro-protein rich secretion that hardens and forms the koilin membrane also known as the cuticula gastris. This membrane and the swallowed small stones, grit, and sand grains facilitate feed grinding and compensate for the lack of teeth (29, 87, 88).

The intestine is the next segment of the avian digestive tract which, similarly to the mammalian intestine, consists of the small intestine and the large intestine. The small intestine is divided into three parts: the duodenum, the jejunum, and the ileum. The large intestine contains two ceca and a straight rectum that terminates in the cloaca. The pancreas is situated in the duodenal loop. The duodenal papilla in the distal part of the duodenum is a point where the bile ducts and pancreatic ducts drain. Food is digested in the small intestine (digestion of proteins, carbohydrates, fats) and absorbed in its distal part (absorption of amino acids, simple sugars, fatty acids). These processes involve enzymes secreted by the proventriculus, the intestinal wall, bile, and pancreatic juice (autoenzymatic digestion). Alloenzymatic digestion involving microbial enzymes, absorption of water and B vitamins, and partial decomposition of fiber takes place in the ceca and the rectum (87). These complex physiological processes are also regulated by hormones secreted by the cells of the gastrointestinal endocrine system (1, 87, 88).

The stability of pH plays a key role in the physiology of the avian gastrointestinal tract because low pH levels can inhibit the growth of pathogens and enhances performance in poultry. The avian proventriculus has a pH of around 4.7, and the gizzard – around 2.0-2.2. Subsequent parts of the gastrointestinal tract have acidic pH, ranging from 5.8-6.5 in the duodenum to 6.7-6.95 in the jejunum and 6.5 in the terminal ileum. The pH of the avian digestive tract varies depending on the type of ingested food. For example, gastric pH was determined at 4.2 in birds whose diets were supplemented with meat and bone meal, and at 1.71 in birds fed oats (75). The pH significantly affects the composition of gut bacterial microbiota, which is an important determinant of bird health and productivity. Changes in gastric and intestinal pH can decrease the diversity of the gut microbiome. The ingested feed stimulates gastric acid secretion; therefore, sudden dietary changes can disrupt gastric acid production, alter the composition of the gut microbiota, increase the risk of digestive disorders, and compromise the health and welfare of poultry.

The gut microbiota of poultry consists of a large and diverse pool of beneficial microorganisms (bacteria, viruses, protozoa, fungi) that are essential for digestive function as well as overall health (2, 38, 47, 89). However, the avian digestive tract can also be colonized by potentially pathogenic microorganisms referred to as pathobionts. Bacterial counts in the gastrointestinal ecosystem have been determined at 10^7-10^{11} cells per 1 g of content (2). The gut microbiota consists of millions of bacteria (more than 640 bacterial species belonging to 140 genera), many of which have not been identified or classified yet (62). The avian gastrointestinal tract is colonized predominantly by Gram-positive obligate anaerobes (*Lactobacillus*, *Biofidobacterium*, *Eubacterium*, *Propionibacterium*, *Clostridium*), Gram-negative obligate anaerobes (*Fusobacterium*, *Bacterioides*), facultative anaerobes of the genus *Streptococcus*, and other bacteria (*E. coli*, *Enterococcus* spp.). These bacteria cover the intestinal mucosa and prevent the colonization and proliferation of pathogenic bacteria (38). Next-generation oligosaccharides, including mannan-oligosaccharides, can enhance the protective effects of beneficial microbiota. By acting as receptor analogs, oligosaccharides bind to pathogenic bacterial cells with mannose-sensitive (MS) type 1 fimbriae (F1), thus preventing these microorganisms from adhering to the gastrointestinal mucosa (40).

The abundance and type of bacteria in different parts of the avian digestive tract vary, depending mainly on the distance from the stomach, where bacteria are generally absent due to a very low pH. Lactobacilli (*Lactobacillus* spp.) predominate in the proximal segment of the small intestine with a more acidic pH (duodenum), whereas distal segments (jejunum) are also colonized by *E. coli* and bacteria of the genera *Streptococcus*, *Staphylococcus*, *Eubacterium*, *Propionibacterium*, and *Fusobacterium*. Bacterial counts have been estimated at 10^7/g in this part of the small intestine, and they are higher (10^{11}/g) in the ceca and rectum, which are colonized mainly by bacteria of the genera *Enterococcus*, *Streptococcus*, *Bifidobacterium*, *Clostridium*, and *Campylobacter*, as well as *E. coli* (2).

The gut microbiota plays a key role in the optimal growth and development of birds, and it also influences the development and the biochemical and immune functions of the gastrointestinal system. Microbial antigens and food antigens modulate cytokine production by enterocytes, leukocytes, and dendritic cells (DCs), and stimulate the development of the immune system (66). Acidic mucins produced by goblet cells play an important role in bacterial translocation, and early colonization of the intestine by beneficial bacteria has a decisive impact on the composition of the gut microbiota (17). Microbial metabolites such as short-chain fatty acids are beneficial to the host, have antibacterial effects, modulate the secretion of pancreatic juices and bile, provide energy for the proliferation of enterocytes, influence mucus production, as well as gene expression (62). These functions are largely determined by the type of diet. Carbohydrate fermentation produces beneficial short-chain fatty acids, whereas protein fermentation leads to the production of toxic metabolites containing sulfur, ammonia, phenolic compounds, and indoles. Carbohydrates are fermented in the proximal segments, whereas proteins are fermented in the distal segments of the intestine (15).

The bacterial microbiota participates in food digestion by producing enzymes, amino acids, B vitamins, and vitamin K, and it also inhibits the growth of pathogens. Bacteria of the genus *Lactobacillus* synthesize antibacterial substances (e.g. bacteriocins), β-glucanases, and compounds for the conversion of bile salts (62). In addition, *Clostridium perfringens*, *Enterococcus faecium*, *Streptococcus bovis*, and *Bacterioides* spp. degrade indigestible polysaccharides in cereal grains. Lactobacilli produce large amounts of lactic and acetic acids to maintain the acidic pH of intestinal content and inhibit excessive growth of pathogenic microbiota. Sudden dietary changes and low-quality feeds increase *E. coli* counts and decrease the abundance of *Lactobacillus* spp. As a result, the pH increases to 7.0 or more, which contributes to the growth of *E. coli* and increases the risk of colibacillosis. In healthy and properly fed birds, lactobacilli always outnumber *E. coli* in the small intestine. These observations suggest that the pH of intestinal digesta should not exceed 6.8 to promote the growth of beneficial rather than pathogenic microbiota and to effectively prevent enteropathies and diarrhea that is difficult to manage in poultry farms (38). Avian gastrointestinal physiology and function are affected by pH, which determines the composition of the gut microbiota. Therefore, the microbial ecosystem of the avian digestive tract is highly susceptible to changes in diet and pH, and the microorganisms that make up the gut microbiota in a given environment enter into mutual interactions.

Recent research has shown that the gut microbiome, composed of diverse microbial communities, exerts a crucial influence on various aspects of animal welfare not limited to nutrient digestion and absorption (28). In addition, the gastrointestinal tract and the central nervous system (CNS) are connected by a bidirectional communication network known as the gut-brain axis, which includes neural, hormonal, and immune signaling pathways. These multifaceted interactions regulate various physiological processes, including immune and behavioral functions. The gut microbiota also affects the activity of the gut-brain axis through neurotransmitters, metabolites, and signaling molecules. Dysfunctions of the gut-brain axis are directly implicated in the pathogenesis of gastrointestinal and neurological disorders in animals, including poultry, and they affect the behavior, stress responses, and overall health status of birds. In turn, imbalanced hormonal signaling pathways disrupt physiological homeostasis and increase the risk of metabolic and behavioral disorders in animals (5, 7, 19, 30, 83).

The immune system of newly-hatched poults is immature, and the optimal adaptive immune responses develops during the first few weeks after hatching (26). During this period, the development of innate immune mechanisms is stimulated mainly through interactions with commensal microbiota (31, 37, 77). The gut microbiome plays an important role in immune response activation, and any disruptions in gut microbial colonization in the first days after hatching can suppress the birds' immunity in later life (68).

In many countries, antibiotics are administered to poults with with drinking water for five consecutive days after hatching, which can negatively affect the composition of the gut microbiota (50, 65). These management practices can contribute to the loss of specific microbial populations and can dysregulate the production of antimicrobial peptides or metabolites that prevent pathogen colonization. Research has demonstrated that antibiotic-induced disruptions in the gut microbiota affect the immune response and can increase the host's susceptibility to infections (35, 48, 52, 59, 76, 84, 85). In addition, many antibiotics exert immunomodulatory effects in birds and mammals (21, 58, 80) by directly affecting various populations of immune cells, the activity of intracellular enzymes, and the levels of cytokines synthesized by immune cells (8, 9, 11, 20, 43, 51, 57, 76, 84).

Antibiotics can disrupt the delicate homeostasis of the gut microbiota, thus affecting the gut-brain axis communication system, secretion of neurotransmitters, and inducing changes in mood and behavior in both humans and poultry (10, 28, 61). Changes in the composition of the gut microbiota can decrease the synthesis and release of neurotransmitters, including serotonin and histamine (30), and can impair the production of short-chain fatty acids, which can interfere with modulation of neuroinflammatory pathways and neurotransmitter synthesis (46). In addition, studies have shown that antibiotics affect the integrity of the intestinal barrier by increasing the permeability of the intestinal wall and facilitating the translocation of bacteria and bacterial metabolites to the circulatory system (74, 81). Coccidiostats can also affect the gut microbiota and intestinal functions, potentially leading to dysfunction of the gut-brain axis (45). These observations indicate that antibiotics and coccidiostats exert systemic effects in poultry by inducing changes in the gut microbiota (10, 61, 70), disrupting the molecular pathways associated with the microbiota-gut-brain axis (25, 28), or even contributing to undesirable behavioral changes such as anxiety and depression (19). These findings show that the relationship between the digestive tract and the CNS is highly complex and that chemotherapeutics have to be administered with caution to prevent disorders leading to reduced productivity, protect animal welfare and the environment, and protect public health by ensuring food safety.

It is worth noting that the gastrointestinal mucosa is the primary site where the host organism comes into contact with the external environment, and it serves as a route by which infectious and potentially harmful agents enter the body. More than 70% of the lymphocytes are located in the gut-associated lymphoid tissue (GALT) (32, 37). Most of them are found in organized structures, but many lymphocytes are also present within the mucosal epithelium (intraepithelial lymphocytes) and in the lamina propria of the mucosa in all parts of the intestine. Therefore, the intestinal mucosal immune system plays a key role in protecting the body against harmful external agents. This system is also responsible for tolerance to food ingredients (dietary antigens) and the antigens of non-pathogenic bacteria colonizing the intestines. During the evolutionary process, higher organisms have „learned" to identify the characteristic structural features of antigens associated with potential pathogens and tolerate the antigens of beneficial gut microbiota (35, 37). These structures are known as pathogen-associated molecular patterns (PAMP). Pathogen molecules are identified by pattern recognition receptors (PRR) (72). The mucosa-associated lymphoid tissue (MALT) consists of lymphoid tissue in the lamina propria and mucosa, which is very well developed in the gut (Gut-Associated Lymphoid Tissue; GALT). The GALT produces secretory IgA, a crucial local defense mechanism of mucosal immunity. The GALT is composed of T cells, B cells, natural killer (NK) cells, dendritic cells (DCs), goblet cells, plasmocytes, macrophages, and heterophils. However, the immune response leading to systemic mucosal immunity is induced in organized lymphatic structures, namely Peyer's patches (PP). Peyer's patches are composed of lymphoid follicles with germinal centers dominated by B and T cells, plasmocytes, and DCs (71). The top parts of PP do not possess intestinal villi, while a characteristic feature of the epithelium covering them is the presence of microfold cells (M cells), which are part of the follicle-associated epithelium (FAE). The name of M cells can be attributed to the presence of microfolds on their apical surface (49). M cells are specialized cells that capture and transport macromolecules and microorganisms from the intestinal surface into the mucosa, where they are presented to lymphocytes by macrophages and DCs (71). In addition to Peyer's tufts, clusters of lymphatic structures also occur in the lamina propria, cecal tonsils, and Meckel's diverticulum. During the immune response, GALT lymphocytes come into contact with antigens and contribute to systemic immunity, including in the mucosa of other systems and organs, which clearly indicates that GALT structures cooperate with other structures of the immune system. Activated lymphocytes migrate from GALT to other structures of the immune system, including the spleen, bone marrow, tonsils, and Harderian glands (6). In the digestive tract, these systemic mechanisms are complemented by highly effective barriers formed by the mentioned low pH of gastric acid, gastric juice components, and the gut microbiota (71).

In commercially farmed poultry, the physiological functions of the gastrointestinal tract can be disrupted by both infectious and non-infectious agents. Therefore, gastrointestinal disorders in poultry have a complex etiopathogenesis. Enteropathies in poultry generally fall into two categories: non-infectious and infectious (38).

Non-infectious enteropathies can be caused by both insufficient and excessive intake of vitamins and minerals, low quality of water and feed, or sudden dietary changes. The type of feed affects the pH of intestinal digesta, which should not change by more than 0.15 (27). Even short fasting periods, ignoring farm hygiene practices (contaminated feeders and drinkers), uncontrolled administration of chemotherapeutics from the first day after hatching, and low animal welfare standards can lead to enteropathy. Animal stress contributes not only to gastrointestinal disorders, but also to systemic dysfunctions. In vertebrates, central mechanisms of physiological regulation, including hormonal mechanisms such as prolactin levels, promote adaptation to environmental changes. On the one hand, changes in prolactin levels affect responses to environmental stressors, and on the other hand, environmental stressors influence circulating prolactin levels in poultry (1). Therefore, a holistic approach to the treatment of enteropathies involves not only the elimination of the causes of gastrointestinal conditions, but also the observance of high welfare standards in poultry farming. The health status of poultry flocks should be assessed mainly based on performance indicators, which usually deteriorate before the first clinical symptoms of disease are observed. The genetic potential of poultry can be fully harnessed only when birds do not suffer physically or mentally, are free of stress, and are able to manifest their natural behaviors. Stress is defined as the body's metabolic response to unfavorable conditions (low welfare), and the stress-induced decrease in productivity is directly proportional to stress levels. Stress also suppresses the immune system's ability to fight off infections (34). The immune response is also a stressor in itself, and the release of cytokines in response to an infection affects metabolic processes, decreases appetite, and reduces productivity (34). For this reason, the immune response should be adequate to the epidemiological threat, as an overactive immune response can undermine productivity, while a weak immune response does not provide effective protection against infection; therefore, the immune response should be modulated (42, 78, 79, 81). Accumulated stress decreases productivity in poultry farms, especially when the stress threshold has been exceeded. In view of the above, the definition of gastrointestinal health in poultry should be expanded to include the phrase "free of stress." In this context, greater attention should be paid to environmental factors that increase disease susceptibility, as these are the key determinants of profitability in intensive poultry farming (39).

In turn, infectious enteropathies are caused by bacteria, viruses, parasites, fungi, and their metabolites. Mixed infections caused by two or more pathogens can also occur, and they are also influenced by non-infectious agents. For example, dietary factors play an important role in infections with anaerobic bacteria of the genus *Clostridium* (*C. perfringens*). *Clostridium* bacteria can be part of the normal gut microbiota in birds, and only drastic changes in the gastrointestinal ecosystem can trigger a series of reactions leading to necrotic enteritis (NE). Dietary changes are most conducive to the proliferation and virulence of *C. perfringens*. Diets rich in cereals such as wheat, barley, oats, and rye slow down digesta passage, increase digesta viscosity, contribute to the proliferation of *C. perfringens*, promote fermentation, and increase the risk of NE (41). Glycine-rich dietary proteins stimulate the growth of pathogenic bacteria such as *C. perfringens* (14), and indigestible feed ingredients can act as substrates for gut microbes (60). Research has shown the dietary inclusion of 10% whole wheat stimulates gizzard function and peristalsis, and modulates immune mechanisms (33, 82).

Avian enteropathies with an infectious etiology can be classified as specific or non-specific. Specific enteropathies are caused by pathogens with high affinity for the gastric mucosa. This group of diseases includes NE, chronic salmonellosis and colibacteriosis, campylobacteriosis, candidiasis, hemorrhagic enteritis, and infections caused by aviadenoviruses, coronaviruses, astroviruses, reoviruses, caliciviruses, circoviruses, rotaviruses, toroviruses, parvoviruses, and picornaviruses (12, 13, 22, 53, 64, 67, 86). These infections pose the greatest danger in turkey farms, and poults are also at risk of developing multifactorial gastrointestinal diseases such as the poult enteritis complex (PEC), poult enteritis mortality syndrome (PEMS) (3, 12), and gizzard erosion caused by adenoviruses and dietary factors (54, 55). The PEC is caused mainly by coronaviruses and astroviruses, but *E. coli*, *Cryptosporidium meleagridis*, *Candidia albicans*, and non-infectious agents also play a role in its etiology (3). The "light turkey syndrome" (LTS) is a term that has been recently coined in the literature to describe birds with lower-than-expected BW gain due to PEC (56).

Parasitic infections of the avian digestive tract constitute a separate group of diseases. These infections are caused by coccidia, flagellated protozoans (*Cochlosoma anatis* and *Spironucleus meleagridis*, which infect the small intestine, particularly in the summer), *Histomonas meleagridis* (a parasitic protozoan that infects the cecum and the liver), roundworms, tapeworms, and Acanthocephala (38).

Non-specific gastrointestinal infections accompany all infectious diseases that commonly cause sepsis (proliferation of bacteria in the blood) and damage to the small intestinal mucosa. This group of diseases includes pasteurellosis, erysipeloid, listeriosis, staphylococcosis, and streptococcosis (38).

The discussed conditions provide only superficial evidence of a much larger problem because enteropathies have a highly complex etiopathogenesis in poultry. Enteric pathogens, in particular viruses, proliferate in intestinal crypts, lead to enterocyte necrosis and villous atrophy. The remaining enterocytes in uninfected Lieberkühn crypts proliferate rapidly to produce biochemically immature enterocytes, which decreases the production of enzymes involved in digestion and absorption. These processes decrease BW gain, lead to vitamin and mineral deficiencies, diarrhea, and pododermatitis, increase the FCR, inhibit the development of young birds, and increase mortality (23, 24). Adverse changes are also observed in the intestinal lymphatic system (intense leukocyte infiltration), which leads to disruptions in the intestinal mucosal barrier (36). These conditions are most prevalent in young birds in the first weeks of rearing, and they cause significant losses in productivity and profitability.

In summary, enteropathies in poultry are complex disorders related to the function of the microbiota-gut-brain axis that require a holistic therapeutic approach. To achieve this goal, poultry should be reared according to the requirements for different species and types of birds, and in observance of welfare and biosecurity standards. Disease specific prevention programs for poultry farms should be developed individually based on the epidemiological situation in a given region. Poultry should receive complete and balanced diets composed of high-quality ingredients. The pH and the gut microbiota significantly affect gastrointestinal function and the microbiota-gut-brain axis, which is why sudden changes in poultry diets should be avoided, antimicrobial agents should not be administered to prevent bacterial infections, and the use of antibiotics should be generally limited in poultry farms. Antimicrobials should be replaced with enzymes that stimulate digestion, feed acidifiers, competitive exclusion cultures, probiotics, synbiotics, innovative preparations combining probiotics with phytoncides, phytogenic feed additives containing natural bioactive compounds with health-promoting properties, and immunomodulators, especially in periods when the immune system is weakened.

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Corresponding author: Prof. Dr hab. Andrzej Koncicki, Oczapowskiego 13, 10-719 Olsztyn, Poland; e-mail: koncicki@uwm.edu.pl