Maximising gut health for peak performance

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The objective of this article is to summarise the post-hatching development of the gut and to discuss its adaptation to changes in diet and stress. The gastrointestinal system responds to the changes that accompany the growth of the animal, the stresses of its environment and the feeding of various dietary ingredients and additives.

This article will cover the early development of gut structure and effects of stresses and dietary changes on that development. The discussion will also include effects of ingredients such as oxidised fats introduced after the gut is relatively stable at one or more weeks of age.

Research has demonstrated the enormous changes in the structure and function of this organ system during the first week after hatching and in its adaptation to environmental and dietary changes later in life.

Results suggest that the more mature gut is responsive to environmental conditions and dietary ingredients and this may be reflected in the bird's growth and financial performance.

The gastrointestinal (GI) tract is the primary site of entry for any orally administered compound, including dietary ingredients. The functions of this organ system include digestion, absorption, and protection, and the structure of the gut is well adapted to perform these functions. The gut provides a barrier to the invasion of the commensal and opportunistic microflora.

The barrier consists of a layer of mucin overlying the gut epithelium, the epithelial cells themselves with their impermeable cell to cell tight junctions and also the innate and adaptive immune cells in the connective tissue below the epithelium.

The mucosa of the gut is the first tissue to encounter dietary ingredients and contaminants and studies of its macroscopic and microscopic structure have been used to clarify the initial response of the animal to these materials.

For example, it is well recognised that the presence of histamine and other biogenic amines in feeds can lead to macroscopic alterations in the gut, including ulceration and haemorrhage in the gizzard and intestine. It is abundantly clear that such severe structural changes have important effects on performance.

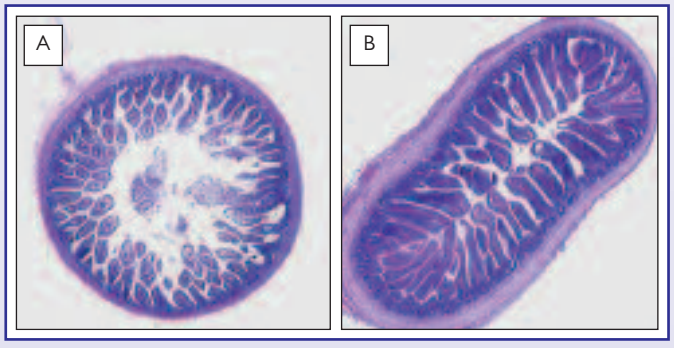
What is less clear is whether lower dietary concentrations of toxic ingredients or factors such as heat or feed restriction cause microscopic effects and whether these could also influence performance, but to a lesser degree.

The adaptive response of the gut itself to dietary ingredients has important implications for bird performance. Intestinal epithelial cells have a very high metabolic rate to support their secretory and absorptive functions and are constantly being renewed by stem cell proliferation in the crypts of Lieberkuhn. During the first weeks of life, the enormous growth of the GI system not only far exceeds that of other organ systems, it is essential if the bird is to achieve its genetic potential.

For these reasons, damage to the gut mucosa can raise the bird's maintenance requirement significantly, leaving fewer nutrients for growth. The gut-associated lymphoid tissue (GALT) also demands nutrient support for metabolism and proliferation, and the unnecessary stimulation of this tissue by hyper-sensitivity reactions to dietary ingredients or sudden changes in the gut microflora also diverts nutrients that could be used for growth.

Thus, studies of the microscopic response of the GI system to dietary ingredients and additives may help to determine the optimum ingredients and additives required to achieve maximum nutrient efficiency and preserve gut health and integrity.

Fig. 1. Cross section of small intestine from chicks fasted (A) or fed Oasis hatchling supplement (B) for the first 48 hours after hatch (mag 20x, H&E). Villus length is clearly shorter in birds provided no enteral nutrition.



Gut development

The gastrointestinal system of a hatchling must undergo tremendous change before it is capable of efficiently digesting many of the ingredients in a typical poultry diet. The first and most obvious limiting factor is surface area for absorption. During the first 5-7 days post hatch, the growth of the gastrointestinal system may exceed that of the rest of the body by as much as five-fold.

Interestingly, the microvilli of enterocytes also increase in length during the first week of life, suggesting that the initial growth of the bird may be limited by the surface area of the gastrointestinal system.

An important correlate is the relationship of gut organ development and the bird's growth rate. Lilja (1983) reported that avian species with high growth rate capacities were also characterised by a rapid early development of the digestive organs and liver. The converse was true for birds with low growth rate capacity, such as quail. Similarly, birds selected for a high eight week body weight were shown to have a greater relative weight of gastrointestinal tract at day 10 than did birds selected for low eight week body weight.

Finally, birds with faster growth rates were reported by Nitsan et al to also secrete high levels of digestive enzymes, although Noy and Sklan reported data to suggest that digestibility of starch and lipids are not limiting factors in the growth of young broilers.

Despite the strong genetic compo-

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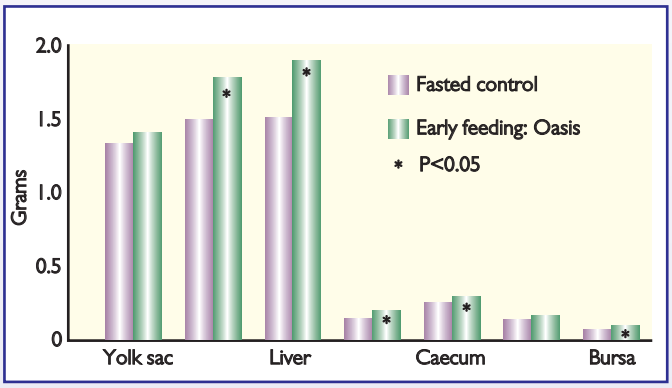

Fig. 2. Weight of digestive organs seven days post hatch in broilers fasted or fed Oasis hatchling supplement for the first 48 hours after hatch. Virtually all organs in the gastrointestinal tract show a trophic response to early nutrition.

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nent in gut growth and enzyme secretion, it is clear that dietary factors can influence this early development. For example, feeding hatchlings selected for low eight week body weight a diet containing 20% more crude protein and 20% more metabolisable energy than the control diet resulted in a significant increase in levels of pancreatic chymotrypsin and lipase.

Force feeding young birds increases the secretion of digestive enzymes in parallel to the increase in food consumption. In addition, poults fed a diet containing no added fat developed higher maltase and isomaltase specific activities than birds fed diets supplemented with either corn oil or tallow.

ved that the time from hatching to the onset of feeding plays a critical role in achieving the genetic potential of the hatchling for growth. We have also found that supplying the specific nutritional needs of the hatchling in the form of a hydrated nutritional supplement (Oasis hatchling supplement) can substantially improve post-hatching performance of birds not immediately provided dry feed, and that growth benefits can be observed through market weight.

Fig. 1 shows the effect of Oasis feeding on gut structure. It is clear that the growth of the small intestine during the first days of life is very responsive to this source of water, highly available carbohydrate, protein, and organic acids.

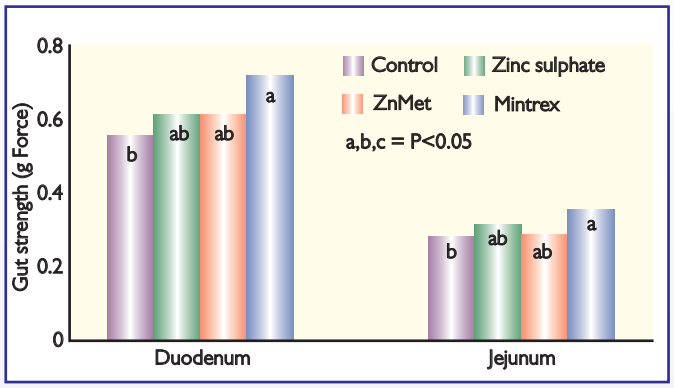


Fig. 3. Breaking strength (kg force) of duodenum and jejunum from birds fed zinc deficient, zinc sulphate, zinc methionine or Mintrex zinc. Only Mintrex gave significantly greater gut strength compared to tissue from birds fed the zinc deficient basal diet.

The fact that birds raised in a germ free environment for seven days have a reduced villus length and crypt depth suggests that normal growth and health of the gut is also affected by the presence of intestinal microflora or their metabolic products.

Effect of early nutrition

From a performance standpoint, a delay in the initiation of feed and water intake can have long term consequences. The practice of holding birds in the hatcher for up to 48 hours or until more than 90% of chicks have emerged from the shell is associated with higher mortality, lower placement weight, and poorer performance in comparison with birds removed immediately after hatching. There is also an indication that immune status may be compromised by delaying placement of hatchlings.

Experiments in which hatchling birds were either fed or fasted indicate that oral intake of nutrients is as important as the residual yolk in the initiation of body weight gain in the bird.

During the process of studying early nutritional needs of hatchling poultry we have repeatedly observed that different components of the digestive system and the gut associated immune system are also significantly affected by early nutrition. The importance of early feeding on future gut health cannot be denied. Early activity and oral nutrient intake are essential components of a good start for the bird.

Organic trace minerals

Virtually all poultry feeds contain supplemental trace minerals. The importance of the form of the supplemental minerals, however, is often overlooked. The advantage of organic trace minerals over inorganic salts is that the binding of the mineral to the organic ligand provides stability of the complex in the upper gastrointestinal system.

Organic trace minerals resist dissociation in the crop, proventriculus and gizzard, thus allowing the intact complex to be delivered to the absorptive epithelium of the small intestine. The organic forms of many minerals, including zinc, copper and manganese are widely used in animal agriculture.

The increased availability of organic minerals compared to inorganic forms has been demonstrated. It should be noted that levels of

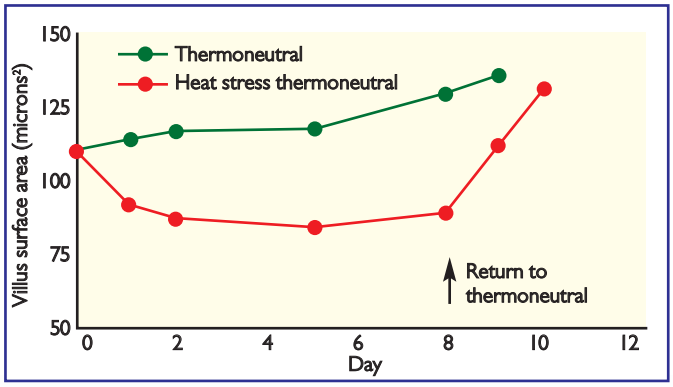


Fig. 4. Villus surface area in small intestine from birds maintained at 22°C or heat stressed (30-32°C) and then returned to 22°C after eight days. Heat stress is associated with a significant shortening and thinning of intestinal villi, resulting in a reduction in surface area and loss or transporters for nutrient absorption. Re-growth following a return to thermoneutral conditions takes approximately three days.

other dietary minerals will affect relative mineral bioavailability and also that different organic ligands will not necessarily increase the bioavailability of a given mineral to the same extent.

The next section of this article will include results using organic sources of zinc, made with either 2-hydroxy-4-(methylthio)butanoic acid (Mintrex zinc) or dl-methionine (ZnMet) as the organic ligand.

Zinc is an essential micronutrient, and is required for a variety of biochemical and cellular processes in all animals. Zinc is the most common metal constituent of cellular enzymes and, as such, plays an essential role in cell proliferation and death, immune development and response, reproduction, gene regulation, and defence against oxidative stress and damage. Collagen synthesis rates are decreased during zinc deficiency, indicating a role for zinc in the synthesis of this protein.

Collagen is a major component of the extracellular matrix and connective tissues, and serves to provide tissue and bone strength. Thus, a zinc deficiency may negatively impact tissue and bone strength.

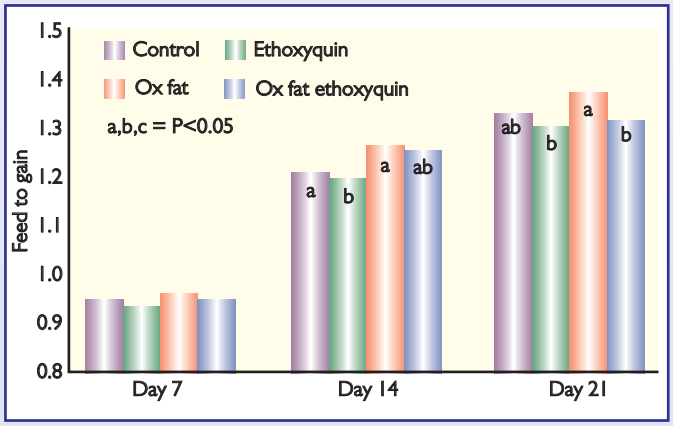
In order to study the effect of organic zinc on intestinal structure, broilers were assigned to four dietary treatments:

- Treatment 1 was fed a zinc deficient basal (milo-soy) diet analysed to be 35ppm zinc.
- Treatment 2 contained 70ppm zinc from zinc sulphate.
- Treatment 3 received 70ppm from zinc sulphate and 35ppm zinc from ZnMet.
- Treatment 4 received 70ppm from zinc sulphate and 35ppm zinc from Mintrex zinc.

Intestine breaking strength was measured on day 28 (jejunum) and 29 (duodenum). As shown in Fig. 3, the zinc sulphate and zinc methionine treatments numerically increased IBS in both tissues, but only the birds fed Mintrex zinc exhibited a significant increase in IBS in both duodenum and jejunum.

One likely explanation to understand these results is that the rates of collagen synthesis and turnover in the control birds may have been low due to the zinc deficiency. Addition of zinc, especially zinc from Mintrex zinc, may have improved these rates of synthesis and turnover, leading to

Fig. 5. Feed efficiency in birds fed a diet containing control or oxidised fat with or without ethoxyquin antioxidant. Birds fed diets containing oxidised fat with no antioxidant had poorer feed conversion than birds fed control fat or oxidised fat in diets containing an antioxidant (ethoxyquin at 125 ppm).



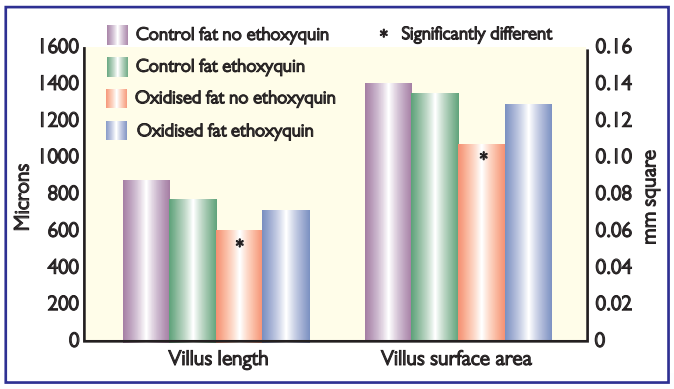


Fig. 6. Microscopic measurements of the small intestines of birds fed control or oxidised fat with or without ethoxyquin antioxidant at 125ppm. Villus length and surface area were significantly reduced in intestine from animals fed oxidised fat without the presence of an antioxidant (ethoxyquin at 125ppm).

greater strength of the collagen rich sub-mucosal connective tissue.

These results indicate that Mintrex zinc may reduce carcase condemnation by reducing intestinal rupture during the evisceration process.

Gut health: heat stress

Much of the world's poultry industry is concentrated in places with year-round or seasonally high environmental temperatures and, consequently, heat stress represents a significant problem to poultry producers. The response of birds to nutrients depends on the severity of heat stress as well as the time of exposure to high temperatures.

Likewise, birds under intermittent heat stress (only a few hours of high temperatures per day) may respond differently than those under constant heat stress. The capacity of birds to acclimate may also affect their response to nutrients.

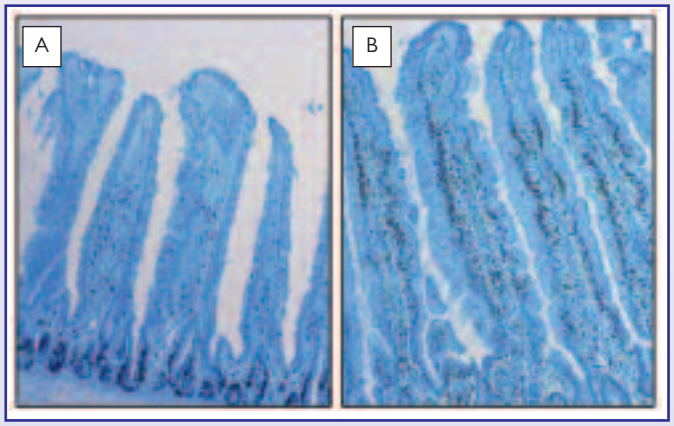
Therefore, in trying to understand the effect of dietary manipulations on the performance of heat stressed birds, the time of exposure, the severity of heat stress and previous exposure to high temperatures should be considered.

After heat stress, birds have the capacity to partially compensate the growth retardation that occurs at high temperatures, as long as favourable conditions and good nutrition are provided. Periods of heat stress followed by periods of recovery may be common in practice since fluctuating high temperatures occur in many poultry producing countries. Providing good nutrition and management during the recovery phase of heat stress is critical to ameliorate the collective effect of fluctuating high temperatures.

Given the fact that birds increase protein retention during periods of compensatory growth, the requirements of birds for key amino acids may increase during the recovery phase of heat stress.

Therefore, providing adequate nutrition during that phase may be critical for managing heat stress. Part of the effect of heat stress on performance can be explained by the physiological changes that occur in the animal.

Fig. 7. Microstructure of small intestine from birds fed bromodeoxyuridine (BRDU). Sections were stained using a monoclonal antibody to detect the cells in DNA synthesis at the time of labelling. Sections of small intestine were from 24 hours (A) or five days (B) post BRDU treatment. Proliferating stem cells for the intestinal epithelium are located at the base of the villi and migrate up the villi over their 5-7 day lifespan.



One important factor in heat stress is the effect on the small intestine. Small intestinal villus length and overall surface area decrease during periods of high temperature (Fig. 4). It is possible that this is due to the higher temperatures per se, but it is more likely that the intestinal structural changes are due to reduced feed intake. Indeed, these effects can also be achieved by fasting.

Regardless of cause, the reduced length of intestinal villi does not recover until three days after return to thermoneutral (Fig. 4).

Recall that the gut epithelium is not fully functional immediately after cell division but requires a period of time, typically two to three days, to mature. This may play a role in limiting the ability of the bird to exhibit accelerated growth.

It is clear that a reduction in absorptive cells could limit the ability of the bird to absorb nutrients whose uptake requires transport across the intestinal epithelium.

The loss of gut structure seen with heat, feed restriction and many other stresses has important consequences for nutrients requiring protein based transport systems to enter the cell.

These limiting nutrients can restrict post-heat compensatory growth and be responsible for a failure of performance to return to that seen in birds under thermoneutral conditions, as has been seen with d-methionine.

Ingredient degradation

Several reports indicate that animals fed oxidised fats can exhibit poor performance, including decreases in gain and feed efficiency in rats and broilers.

It has been demonstrated on numerous occasions that animals require certain polyunsaturated fatty acids and that deficiencies can be associated with weight loss, fatty liver, kidney malfunction and poor reproduction.

It has also been demonstrated that dietary oxidised fats can become incorporated into cell membranes, liver cells and adipose tissue, and that feeding oxidised fat reduces the amount of tocopherol present in subcellular membranes.

Vitamin E deficiency results in histopathological changes in a variety of tissues including immune organs such as bursa, thymus and spleen, vascular tissues and erythrocytes, muscle tissue and the nervous system.

Effects on gastrointestinal microscopic structure have not been emphasised, despite the fact that this is the first organ system to encounter the oxidised material.

The objective of the research conducted at Novus was to study effects of oxidised fat on gastrointestinal structure and function. Birds were fed diets containing control or oxidised fat with or without ethoxyquin added at the time the feed was mixed.

In addition to performance differences, a variety of effects of oxidised fat on the gastrointestinal system were detected in this study, including changes in nutrient uptake, intestinal microflora, and the gut associated lymphoid tissue.

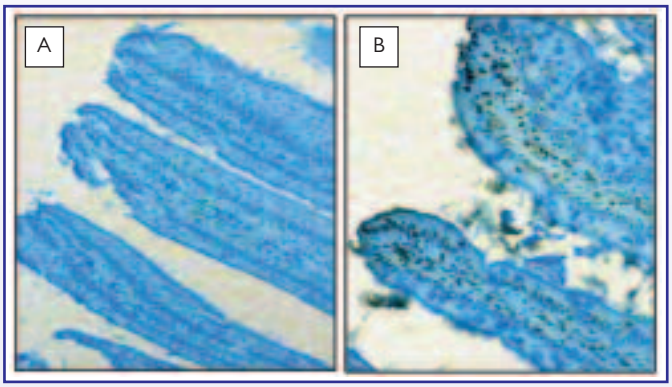


Fig. 8. Microstructure of small intestine from birds fed oxidised (A) or control fat (B) and treated with bromodeoxyuridine (BRDU) to label proliferating cells. Sections were stained using a monoclonal antibody to detect the cells in DNA synthesis at the time of labelling. Section of small intestine were from seven days post BRDU treatment and show that the lifespan of enterocytes from villi of birds fed diets containing oxidised fat is shorter than from birds fed diets containing non-oxidised (control) fat.

Fig. 5 shows the performance effects.

Differences in cumulative feed conversion were detected at 14 (P=0.05) and 21 days (P=0.07).

For both time points, birds fed the stabilised diet containing control (non-oxidised) fat gave the best feed conversion.

This is an important finding because it suggests that the feed needs to be stabilised even when the fat is known to be of good quality and is fed immediately.

Tissues from birds in this study

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were evaluated for microscopic structural changes on days six and 20. Fig. 6 shows the morphometry results at day six.

There was a significant effect on villus length of feeding oxidised fat in the absence of ethoxyquin. This is consistent with the hypothesis that absorptive enterocytes are negatively affected by the oxidised fat in the absence of an antioxidant to protect them from membrane damage.

As with heat stress, a decrease in villus length will increase the proportion of enterocytes which are not yet fully functional, because the amount of time required for differentiation does not change.

A decreased villus length reduces the surface area available for secretion of digestive enzymes and absorption of nutrients and may be a causative factor in the poor performance seen with oxidised fat.

One way to study the effect of oxidised fat on the intestine is to study gut epithelial cell turnover.

As described earlier, the turnover of these cells is very costly in terms of nutrient partitioning to maintenance instead of growth. One method to study cell turnover is to label cells synthesising DNA using an analogue of the DNA component thymidine, bromodeoxyuridine.

Fig. 7A shows the location of the proliferating stem cells in the intestine. They are the dark nuclei in cells found at the base of the villi, in the crypts. Following crypt cell division, the gut epithelial cells migrate up the villus and are shed off the end into the gut lumen.

Fig. 7B shows the location of the cells five days after labelling. They have migrated 75-80% of the length of the villus.

Fig. 8 shows the progression of the labelled cells after seven days. In the gut of the animal fed oxidised fat (Fig. 8A) the labelled cells have died and been lost off the end of the villi. In contrast,

Fig. 8B shows that animals fed the control fat still bear labelled epithelial cells, indicating that these cells live longer when the animal is fed fat that has not been oxidised.

This difference in cell turnover plays a role in the poor feed efficiency seen when oxidised fat is fed.

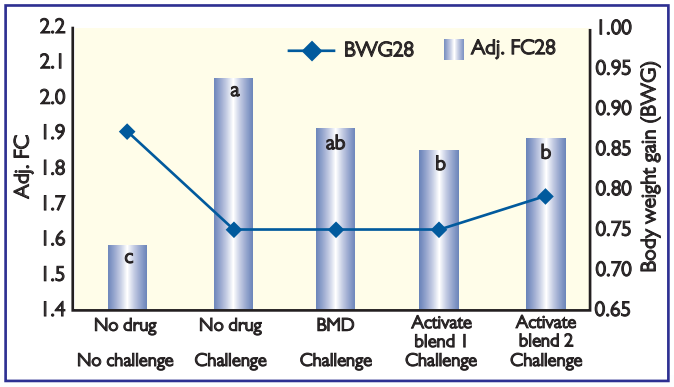

Fig. 9. Mortality adjusted feed conversion and body weight gain in control birds and birds given an antibiotic (BMD) or organic acid blend containing formic acid (Act-EU) or an organic acid blend with no formic acid (Act-US). Birds were challenged with a combination of coccidia (day 14) and clostridia (days 17, 18 and 19) to mimic a necrotic enteritis stress. Organic acid blends have performance equal to the antibiotic treated birds and are significantly improved compared to the challenged controls.

Organic acids and AGPs

Approvals for the use of non-therapeutic antibiotics in animal feed have been withdrawn in several countries and the practice of feeding low dose growth promoters is fast disappearing worldwide. Already, producers who want to sell in the drug free market are searching for non-pharmaceutical replacements for feed antibiotics.

To understand what would be a suitable replacement, an understanding of the mode of action of antibiotics is required.

Most data suggest that the growth promoting effect of antibiotics can be entirely ascribed to their antimicrobial activity and the physiological repercussions from that.

Thus, the search for replacements has focused on naturally occurring molecules with known anti-microbial activity.

Among the most efficacious candidate replacements are organic acids, both individual acids and blends of several acids. Organic acids have a clear and significant benefit in weanling piglets and have been observed to benefit poultry performance.

Orally ingested antibiotics promote growth and efficiency of poultry and other animals. The effect can include gain but often is limited to feed efficiency effects only.

The mechanism of action must be focused on the gut since some of these antibiotics are not absorbed.

Following early demonstrations that oral antibiotics do not have growth promoting effects in germ-free animals, studies of the mechanism for growth promotion have focused on interactions between the antibiotic and the gut microbiota.

This illustrates the importance of the host response to the microflora as another factor limiting growth efficiency.

Additional AGP effects that also occur in germ-free animals include reduction in gut size, including thinner intestinal villi and total gut wall. The reduction in gut wall and villus lamina propria has been used to explain the enhanced nutrient digestibility seen with AGP.

Finally, the reduction in opportunistic pathogens and subclinical infection has also been linked to use of AGP.

Fig. 9 shows the effect of feeding antimicrobial organic acids on the performance of birds subjected to a combined coccidial (day 14) and clostridial (days 18, 19 and 20) challenge. In this experiment, the controls consisted of unchallenged birds (treatment 1), challenged birds (treatment 2), birds challenged but treated with BMD (treatment 3), birds challenged but treated with an organic acid blend containing formic acid (treatment 4) and birds challenged but treated with an organic acid blend with no formic acid (treatment 5).

As shown in Fig. 9, post challenge performance for the non challenged birds was significantly better than for any of the challenge treatments.

Among the challenged treatments, both of the organic acid blends gave performance significantly better than the untreated birds and numerically superior to the antibiotic treatment. Thus, organic acids can be an important contributor in a strategy to reduce us of AGP for high efficiency animal agriculture.

Summary

Studies of the development and function of the gastrointestinal system have yielded enormous advances in our understanding of the interaction between host tissue and the luminal contents of the gut, including digesta and microflora.

The development and maintenance of the gut in poultry and the response of the gut to stress, including feed deprivation, nutrient oxidation and deficiency, heat stress, and disease contribute to the poor efficiency associated with stress situations.

Clearly, implementing feeding strategies for maximising gut health and integrity is essential for peak performance efficiency in modern poultry production. ■