

Feed additives that promote enteric development; with special reference to organic acids.¹

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Introduction

In poultry the early development of the enteric system is considered one of the most crucial steps in achieving life-time performance objectives and maximum economic returns. In the immediate post hatch-period important changes occur in the physiology and function of the chick's gastro-intestinal tract and the associated organs such as liver and lymphoid tissue. In size and weight the small intestine and cecum increase up to 5 times more rapid than most other organs and achieve a maximum relative growth rate at 6-10 days post hatch (Bar-Shira and Friedman, 2005; Katanbaf and Siegel, 1988). The intestinal villi, crypts and enterocytes – essential for effective absorption of nutrients – develop even more rapidly, reaching a relative growth plateau at 48 h post hatch (Geyra A, et al., 2001). In the presence of feed (nutrients) the development is increased and short- as well as long-term performance improved (Bigot et al., 2001; Knight and Dibner, 1988).

Development of the early gastro-intestinal tract (GIT) is also stimulated by the establishment of an active microbial population (Bird et al., 2002). However, it is not clear what the precise contribution of the microbiota is relative to that of its fermentation products. Generally a close symbiotic relationship is assumed but competition for some nutrients between the developing tissue and the microbiota is likely. While the required substrate for microbial development is relatively well known, it is much less clear what the essential and signaling nutrients are that should be supplied to directly stimulate GIT development. Post-hatch colonization of the GIT by micro flora is also an important step in the stimulation and maturation of the immune system. For optimal development of the immune system and maximum performance the establishment of a synergistic relationship between beneficial micro-organisms and the host animal is necessary (Neish, 2002)

Dietary interventions that provide the essential nutrients and conditions in the GIT for accelerated gut development and the establishment of a symbiotic relationship between micro flora and host animal should be part of routine feeding programs. It is clear that the achievement of these early objectives goes beyond classical nutritional requirements and that specific feed additives can play a major role. This paper will address the potential role of some additives in stimulating early enteric development and thus life time performance. Emphasis will be on the role of organic acids from exogenous and microbial origin.

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General.

The number of additives included in poultry diets has increased considerably over the past decennia. More recently this development has received a further stimulus as the use of antibiotic growth promoters (AGP) has been called into question or outright forbidden. The inclusion of additives is primarily based on claims regarding improvements in growth or feed utilization (feed conversion) in growing birds with a particular focus on the end result. Limited information is available on the effect of these additives on enteric development, especially during the first days post hatching. At this stage in our understanding of enteric development the effect of most additives can only be deduced from information obtained on older birds.

Additives improve performance of the gastrointestinal system through their effect on intestinal physiology, gastric pH, secretions in the gastrointestinal tract, immunity and microbial balance or their fermentation products (Thompson and Applegate, 2005). Most of the additives employed are complex in their function and thus address more than one of the above mentioned areas. During the post hatching period emphasis should be on those additives that selectively stimulate growth and function of the villi, crypts, enterocytes and the gut-associated lymphoid tissue (GALT). This will logically result in improved nutrient utilization and a lower risk of pathogenic infection. The latter should not only lead to a reduction in the direct effects due to infections but also reduce the loss of energy or other nutrients. Candidate additives that may play a role in stimulating enteric development are organic acids, fatty acids, enzymes, (chelated) minerals, essential oils and pre- or probiotics. However there is a paucity of information on the precise effects of these additives, their mode of action and potential interactions with AGPs.

AGPs are not considered in the list of “natural” additives because their mode of action is difficult to reconcile with the stated growth and development objectives of the GIT. The presumed mode of action for AGPs has been reviewed (Bedford, 2000) and is considered to be mediated largely through their depressing effect on the natural microbiota in the GIT. This in turn results in:

- reduced activation of the intestinal immune system
- thinner intestinal wall
- increased digestive enzyme output
- reduced gut motility
- reduced mucin secretion
- reduced toxin production (e.g. ammonia and biogenic amines)
- reduced bile salts modification

Most if not all of these proposed effects are contrary to the objectives for a rapid development of the GIT and it is thus questionable if, under normal production conditions of controlled microbial pressure, there is a place for AGPs in post hatching diets. While many of the non-AGP additives will also have specific anti-bacterial effects, they also have a stimulatory effect on growth and development of the GIT.

Post hatching diets and additives.

Evaluation of additives on poultry performance post-hatching is complicated by the fact that their effects are not evident in terms of growth, feed conversion or mortality/morbidity during the first days of life. This has been clearly demonstrated

under repeatable experimental conditions (Bigot et al., 2001; Knight and Dibner, 1998; Azevedo and Dibner 2006). For broilers as well as turkey poults these authors demonstrated that – relative to a fasted control - body weight and feed conversion did not differ for animals provided with a supplement composed of various additives. However, intestinal mass, liver mass and size of spleen was significantly larger. Subsequent weight gain and feed conversion following the post-hatch period was improved. The authors also noted that contrary to later growth retardation in fasted or mal-nourished birds (after 6 – 7 days of life) little if any compensatory growth occurred during the subsequent growth period indicating that the growth delay incurred during the post hatch period is permanent. The same permanent effect appears to apply to the immune system as flock mortality and morbidity remained higher in fasted birds. The precise mechanisms underlying these permanent effects remain unclear but it seems evident that for maximum lifetime performance an early and rapid development of the enteric system is necessary. Growth or immune stimulating additives with a proven positive effect on enteric tissue growth should therefore be included in post-hatch diets.

While many additives have shown a positive effect on growth and immunity in older birds, demonstration of their effect in the post hatch stages are rare. Their effects at this stage have to be judged largely on the basis of the bird's performance later in life. Indeed, because of the apparent permanent effect of early enteric development, evaluation of performance until the end of the growing-finishing cycle could be considered an indicator of early enteric effects of an additive.

The feeding of additives in the post hatch period aims at achieving one or more of the following objectives:

- a. Supply essential nutrients for tissue growth and function – digestive and immune system;
- b. Support absorption and utilization of nutrients from non-additive ingredient;
- c. Regulate the intestinal micro-flora.

The supply of essential nutrients for maximum growth of intestinal structures (villi, crypts, enterocytes) and of the immune system concentrates predominantly on micro nutrients such as vitamins and minerals. Although these nutrients are supplied by the basic diet (raw materials) they may - due to their form - be poorly available or in such low concentrations that the animals benefits from an additional supply. For instance, positive responses have been obtained with chelated minerals (Lee et al., 2001). Although the differences in weight gain, feed intake or feed conversion were small and not noticeable during the first life phase these differences became significant between two and four weeks of age. Azevedo and Dibner (2006) observed that broilers that received a Zn supplemented diet (in the form of Zn-sulfate or Zn chelates) had a greater breaking strength for the duodenum and the jejunum after 28 days. In this respect it is of interest to notice that Lee et al. (2001) measured also digestibility and although the differences between control and the diet with chelates were not significant, average apparent protein digestibility was more than 5.5 %-point higher in the diet with chelates added. The differences in dry matter and energy digestibility were negligible but mineral utilization (Ca, Cu, Zn) was also improved. These nutrients may be retained for greater enteric tissue synthesis.

Besides their role in tissue synthesis, additives that supply essential nutrients such as vitamins and micro- minerals also play a key role in enhancing the immune status of poultry. These nutrients, at higher levels than are generally considered necessary for optimal growth, are considered critical for early immune development (Friedman and Sklan, 1997; Klasing, 1998).

Rather than directly supplying specific nutrients for tissue growth the main focus of many nutritional additives is to facilitate the conditions that lead to improved nutrient absorption and utilization. Emphasis is thus on stimulating and maintaining the integrity of the developing GIT. Important threats to this – especially under conditions where AGPs are not allowed – are opportunistic pathogenic bacteria. Under practical conditions low levels of these enteric bacteria are difficult to control or eliminate. As a matter of fact, a case can be made for a low level presence of a mixed microbial population as the effectiveness of the immune system (maturation) at later stages in the life cycle seems to be conditioned by early contact. In this respect the objective of the additives is to reduce the concentration of harmful bacteria and create a balanced intestinal microbiota. Probiotics, pre-biotics and organic acids are additives that are uniquely suited for this purpose.

Microbial populations, pre-, pro-biotics and organic acids.

In older broilers the GIT is colonized with a diverse and dynamic microbial population. Immediately following hatching the GIT is sterile but becomes rapidly colonized by competing microbial populations and a stable population is only established until after day 49. The sequence in which the various microbial species. colonize the post hatching GIT has been established (Jiangrang et al., 2003). The crop and the cecum present the highest diversity and most complex flora but like all other parts of the GIT they are influenced by the hatching condition, the environment and- especially- diet composition (Thompson and Applegate, 2005; Gabriel et al., 2005). Early colonization of the GIT by beneficial microbial organisms is essential as they generate a luminal environment that provides a barrier to potentially pathogenic bacteria. Competitive exclusion - used for many years as a prophylactic treatment - is based on this very principle. Table 1. shows the reduction in concentrations of salmonella and clostridia in the cecum of 4-day old chicks provided with a mixed culture of micro organisms obtained from adult birds (Dawson, 2001).

Item	Group		
	No CE	CE	Probiotic
Bacterial conc. (log ₁₀ CFU/g)			
Salmonella	3.98	2.31	3.35
Clostridium	3.01	2.02	2.5
Acid conc.(mM)			
Lactic acid	32.5	15.1	27.1
Propionic acid	5.4	12.7	8.91

(Dawson, 2001)

As in all domestic species, in poultry the early enteric microbiota will stimulate the development of the intestinal immune system and provide fermentation products that assure mucosal health and stimulate the development and of the different GIT structures. Regulation of the early microbial population through the supply of pro- and pre-biotics provides the possibility to stimulate enteric development and intestinal immunity. However like pre-biotics, the diet – especially in terms of its carbohydrate components – can have a deciding influence on microbial development and thus the concentration of fermentation end products, the short chain fatty acids (SCFAs) (Gabriel et al., 2005; Thompson and Applegate 2005). Clearly, this requires the presence of a dominant beneficial population of microbes. Inclusion of probiotics will change the composition of the intestinal microbiota and has resulted in improved performance in broilers and turkeys. However, results obtained with pre-biotics seem to indicate that stimulation of the autochthon microbial population is more consistent and as effective - if not more - than changing or adding to the microbial diversity (Fig. 1A, B).

Figure 1A: Relative effects of probiotics on weight gain (% of control) in broilers and turkeys - 22 trials from 7 publications.

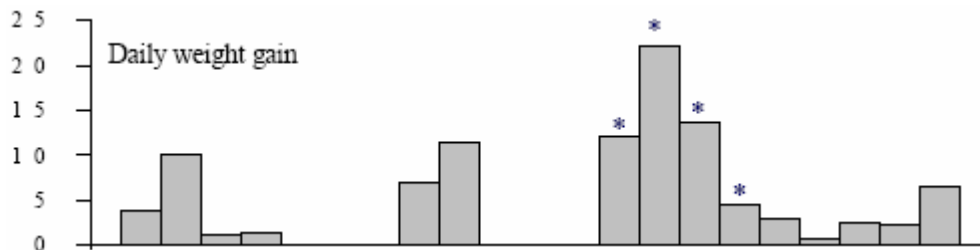
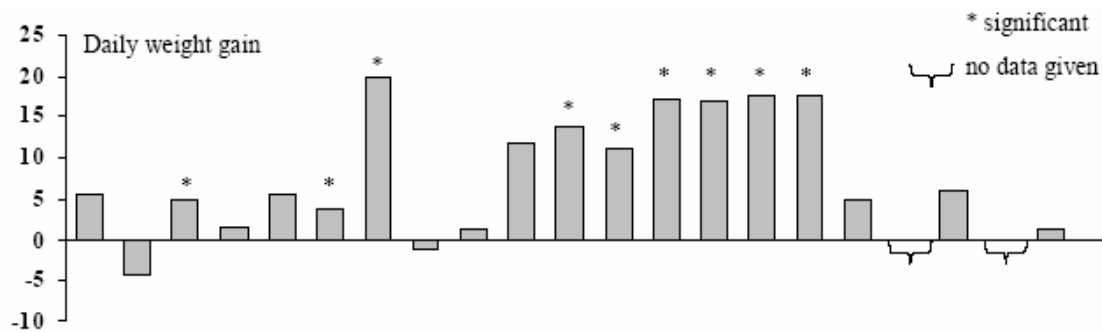


Figure 1B. Relative effect of prebiotics on weight gain (% of control) in broilers and turkeys- 22 trials from 11 publications.



(Simon, and Jadamus, 2002).

The differences between pro- and pre-biotics as presented by Simon and Jadamus (2002) were even more pronounced in terms of feed conversion than for weight gain. Although these were not direct comparisons it seems thus that stimulation of the indigenous microbial population has a greater effect on diet utilization and potentially the development of the GIT than the introduction of non-indigenous microbes. The latter – probiotics - need to be supplied on a regular, day-to-day, basis in order to assure consistent concentrations and persistent presence.

One of the most notable and natural consequences of stimulating the GIT-microbes is the changes that occur in the physio-chemical characteristics of the chime. Among others, an active, stimulated microbial population has been shown to reduce pH and

redox potential while raising osmotic pressure (Gabriel et al., 2005). This is largely the reflection of an active fermentation and parallels the production of volatile fatty acids (VFAs). Changes in production of organic acids and SCFAs have been observed in the GIT of different species upon stimulation by diet or prebiotics. This has led to differences in concentration and pattern of these acids in the GIT of many species (Ferket et al., 2002; Le Blay et al . 1999;Verdonk et al., 2005). However, as expected, acid concentrations differed according to substrate (pre-biotics or diet components), microbial population and fermentation conditions in the host animal. Ferket et al., (1999) evaluating mannan-oligosaccharides (yeast outer cell wall components- MOS) in 12 week old turkeys observed a significant decrease in propionate concentration in the jejunum and no change in acetate, butyrate or lactate. Le Blay et al (1999) noted a significant and long lasting increase in butyrate concentrations and no change in propionate in the cecum of rats fed a diet supplemented with fructo-oligosaccharides. Along with the changes in SCFA concentrations performance enhancement were noted. Verdonk et al.(2005) reviewed a large number of studies in domestic animals and concluded that the effect of pre-biotics on the gut micro flora and gut integrity resulting in performance improvement was undeniable but highly variable. Many of the responses were accompanied by changes in SCFAs. The effect of changes in SCFAs resulting from probiotics (Dawson, 2001; see Table 1) and prebiotics (Van Immerseel et al., 2002) on pathological micro-organisms (salmonella, clostridium) has also been demonstrated.

Since different patterns of SCFA are produced by gut micro-organisms in response to various pre-biotics or diets, responses in terms of physiological or morphological changes will also vary. Among the SCFAs it is especially butyrate that is of interest because of its physiological activity and ability to stimulate gut development (Pouillart, 1998). Butyrate is recognized for its direct effect on mucin secretion, as an energy source for the enterocytes and as an important regulating molecule in enterocyte proliferation (Thompson and Applegate, 2005). Other acids produced by the micro-organisms may have similar effects – although to a lesser degree - or may have different, unique effects. They may also be intermediates in the production of butyrate such as has recently been demonstrated for lactate (Bourriaud et al., 2005) suggesting that also the probiotics lactobacilli may indirectly contribute to the presence of butyrate in the GIT.

Organic acids.

Until relatively recently the use of short and medium chain fatty acids was largely based on their anti-microbial and anti-fungal characteristics outside the GIT (Ricke, 2003). With the removal of AGPs their role as anti-bacterial substance in the GIT was recognized and this effect was originally attributed to their pH lowering effect especially in the crop (Thompson and Hinton, 1997). However, not all acids are equally effective and there is an important difference in minimum inhibitory concentrations (MIC) depending on the type of acid, the targeted microbes and the pH level at the site of action (Nakai and Siebert, 2002). At the same range in pH a number of organic acids are not inhibitory to bacteria while others are. Key to their anti-bacterial action is their characteristic pKa and the degree of dissociation at a particular pH. In general, at low pH values the concentration of undissociated molecules increases. Short chain ($\leq C4$) acid molecules need to be in an undissociated state in order to enter the microbial cell. After entering the cell the higher intra-

cellular pH results in dissociation and lowering of the internal pH thus disrupting normal metabolism (Ricke, 2003). Especially sensitive to this mechanism seem to be gram-negative bacteria such as *E. coli* and *Salmonella* spp, and the gram positive *Clostridium* spp. However lactobacilli (gram positive) are much more resistant. Acids with a low pKa (e.g. formic, lactic) have shown to be effective against *Salmonella* spp. (van Immerseel et al., 2002) and against *Clostridium perfringens* (Gornowicz, 2004). The SCFA (acetic, propionic or butyric) have a greater pH lowering effect due their higher pKa thus favouring the growth of non-pathogenic bacteria such as lactobacilli. However, in the absence of acidification of either diet or drinking water, this requires the presence of an active fermentation. Although establishment of an active microbial population is relatively rapid following hatching, one-day old broilers have only low concentrations of SCFAs in their GIT and their concentrations do not reach stable, mature levels until well after 10 days of age (Van der Wielen et al., 2000). Consequently, inclusion of organic acids in post hatching diets can have a first positive effect on the intestinal micro-flora and the presence of toxic substances produced by pathogenic microbes.

Microbial populations in poultry have been studied and described in much detail (Jiangrang et al., 2003). However studies on the effects of specific additives on these populations are limited and this is certainly true for organic acids. Table 2. shows the effect of a mixture of salts of organic acids on microbial concentration in the ileum and cecum of broiler chicks. The addition of these organic acids at 0.2 % significantly reduced the concentration of total and gram negative bacteria. However this decrease was less than what was obtained with the antibiotic flavomycin. Differences between 21 and 42 days of age were non-existent both in terms of age and treatment effects.

Table 2. The effects of a probiotic, an antibiotic growth promoter (flavomycin), an organic acids mixture or a probiotic + an organic acids mixture treatments to broiler diets on some intestinal parameters, (n=6). (Adapted from Gunal et al., 2006).

Segment, age; log10 cfu/g	Basal diet	Antibiotic (flavo- mycin)	Organic acids mix*	Organic acids mix* + probiotics	Probiotics	SEM
Ileum, 21 d						
Total bacteria,	8.03 ^{ab}	6.61 ^c	7.05 ^{cd}	7.33 ^{abd}	7.93 ^a	0.16
Gram - bacteria,	7.28 ^a	6.11 ^c	6.33 ^{bc}	6.55 ^{bc}	6.71 ^b	0.12
Ileum, 42 d						
Total bacteria,	8.20 ^a	6.16 ^b	7.03 ^c	7.31 ^{ac}	7.95 ^a	0.18
Gram - bacteria,	7.58 ^a	5.61 ^c	6.63 ^b	6.83 ^b	6.93 ^b	0.14
Caecum, 21 d						
Total bacteria,	8.68 ^a	7.10 ^b	7.63 ^{bc}	8.05 ^{ac}	8.53 ^a	0.15
Gram - bacteria,	8.10 ^a	6.81 ^c	6.98 ^{bc}	7.15 ^{bc}	7.45 ^b	0.13
Caecum, 42 d						
Total bacteria,	8.46 ^a	6.53 ^b	7.65 ^c	7.83 ^{ac}	8.13 ^{ac}	0.16
Gram - bacteria,	7.95 ^a	6.06 ^c	7.06 ^b	7.28 ^b	7.33 ^b	0.14

^{a,b,c,d}, Row means with common superscripts do not differ (P<0.05) SEM: standard error of mean.

*mixture of salts of propionic and formic acids (mixed with mineral salts and essential oils).

The decrease in gram negative bacteria is consistent with the well recognized effect of organic acids on salmonella levels. Mixtures of these acids (esp. formic and propionic) have been used successfully for the specific control of Salmonella both in feed (Humphrey and Lanning, 1988) and in vivo (Thompson and Hinton, 1997; van Immerseel et al., 2006). In addition to their effects on salmonella, the controlling effect of organic acids on other pathogenic micro organisms is expected to lead to improvements in performance. Replacement of AGPs by organic acids is at least in part based on this principle although complete replacement by acids alone remains difficult (see Table 2). Positive production responses to various mixtures of organic acids have been reported but results remain variable, not in the least due to the large number of different combinations and forms of the mixtures (Ricke, 2003). Performance enhancements with a mixture of propionic and formic acid (70:30) are shown in Table 3. In this trial performance differences were observed from the first week suggesting that early inclusion of an organic acid mixture may have immediate results including in the post-hatch stages. The differences in weight gain were maintained throughout the 5-week feeding period and although numerical difference became larger, variability increased leading to reduced levels of statistical significance at the end of the feeding period. Thus the effect of this acid mixture is larger and more consistent during the early stages of growth with a diminishing effect later in growth. This seems contrary to the observations of Knight and Dibner (1998) that early improvements in performance will program later results. To what extent the observed responses are due to a shift in microbial populations or a direct effect on GIT function is not known. However, from these results it seems that formic and propionic acids have a limited potential to affect directly and positively early enteric GIT development.

Table 3. Live weight (g) for Broilers fed a control or a control + organic acid mix.

Week	n	Control	Org. Acid.*	Diff. (%)	p-Level
1	120	142	147	3.5	0.01
2	120	368	375	1.9	0.01
3	120	731	773	5.7	0.01
4	120	1194	1263	5.8	0.05
5	120	1662	1759	5.8	0.06

* (combination of formic and propionic acid based on an inorganic phyllo-silicate carrier; included at 3 kg/T). (Adapted from Lückstädt et al., 2004)

For a broad control of the enteric microbial population and to stimulate development of tissue structure the use of other, selected SCFA as additives may be indicated. Since the natural concentration of these acids are low to non-existent in the post hatching GIT (van der Wielen et al., 2000) they may play a role in establishing a beneficial microbiota (notably lactobacilli or bifidobacterium) and accelerating tissue development in the immediate post-hatch stage. In older birds these acids added to diet or drinking water have shown to regulate the microbiotic population, controlling pathological bacteria especially salmonella (Durant et al., 2000; van Immerseel et al., 2006). However they also aid in maintenance of gut integrity and function. Effects of specific SCFAs on microbial populations, digestive function and – to a limited degree - gut morphology have been demonstrated in other monogastric species, specifically swine (Partanen and Mroz, 1999).

Among the SCFAs it is especially butyrate that has attracted attention. Administration of Na-butyrate to milk-fed piglets led to a significant reduction in villi length and mucosa thickness in the duodenum, however, in the distal jejunum and ileum, the crypt depth, villi length and mucosa thickness were increased (Kotuni et al., 2004). Similar observations were made earlier by Gálfi and Bokori(1990).

In broilers, Leeson et al. (2005) compared the effect of butyrate (in glyceride form) to that of bacitracin on villi height and crypt depth following a challenge with coccidial oocysts (Table 4). At 0.2 % butyric acid crypt depth was significantly greater than in control animals. Weight gain of butyrate supplemented animals was also larger. The authors concluded that butyrate helps in the maintenance of intestinal villi structure and that prior treatment reduces the devastating effects of a coccidial challenge. In a parallel study performance of broilers was not affected by butyrate or virginiamycin supplementation of diets.

Treatments	Duodenum (nm)		21 to 27 d weight gain (g)
	Villus length	Crypt depth	
Control	1,428	270 ^a	252 ^b
Bacitracin	1,595	203 ^b	—
0.2% butyric acid	1,562	266 ^a	316 ^a
SD	70	17.9	65

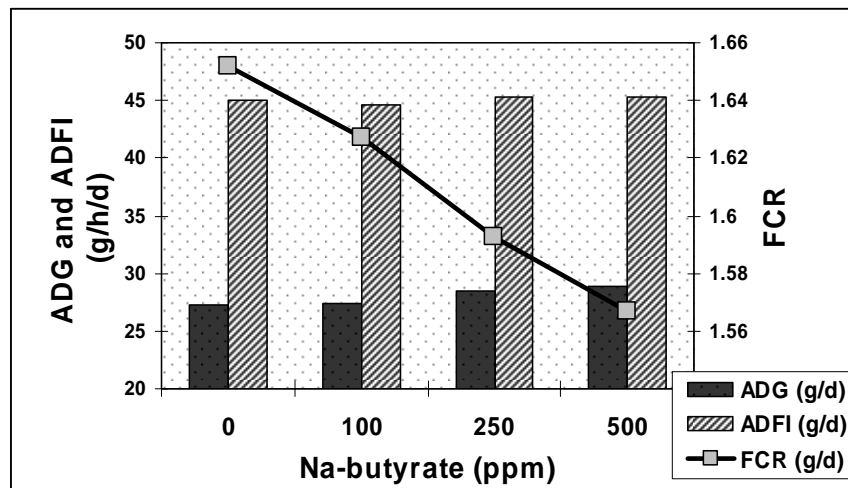
^{a,b}Means followed by different superscripts are significantly different.

The most common form in which butyrate is used is as a salt of sodium or calcium and not as glyceride. Like other organic acids free butyric acid is rapidly absorbed and metabolized in the upper GIT with limited or no effect in the small intestine or cecum. Encapsulated forms of butyric acids reduce this problem and make the butyric acid available along the entire GIT. In addition, encapsulation reduces the characteristic smell associated with the free acid. Results with an encapsulated form of Na-butyrate are presented in Fig 2. In this study weight gain and feed conversion was improved ($P<0.05$) between 0 and 21 d. Results were maximized at an inclusion level of 250 ppm butyrate although further improvements at higher inclusion rates seem to be possible. The characteristic decrease in feed intake often seen with other organic acid supplementation was not observed ($P>0.05$). Continued inclusion of butyrate beyond 21 days had no effect and at 42 days all treatment had similar body weight or feed conversion coefficients. These results seem consistent with an improvement at the early life stages in nutrient absorption related to gut morphology and enterocyte function.

A large body of information exists on the application of butyrate or its derivatives in humans, in particular in reference to its regulatory role in intestinal tissue growth and development. Pouillart (1998) summarized the following functions for butyrate in human nutrition and medicine:

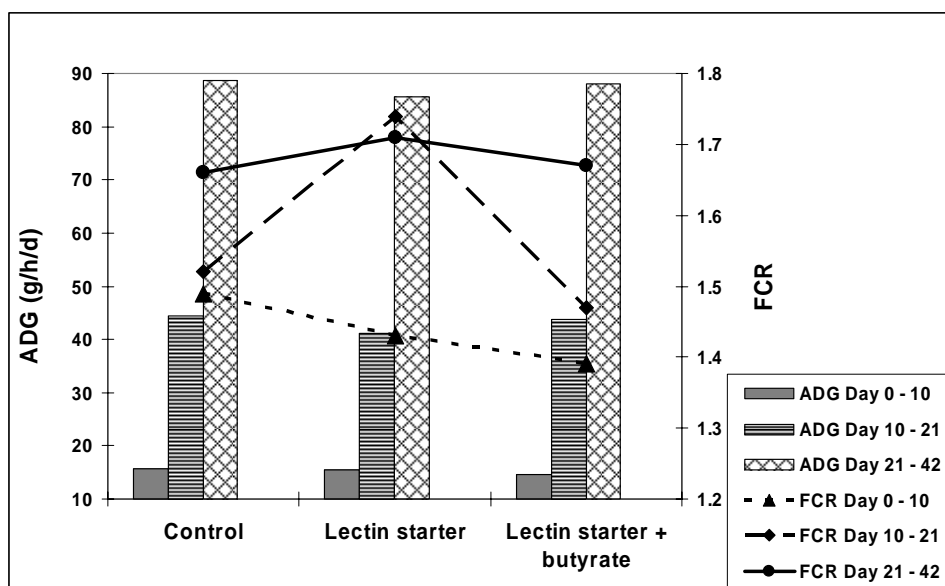
- supply of energy to the intestinal mucosa
- regulation of gene expression in intestinal epithelium
- induction of cell differentiation (enterocytes)
- growth stimulation of colonocytes, enterocytes and basal cells
- increase in contact surface of intestinal villi
- increase of secretion of digestive enzymes
- increase in absorption of Calcium

Fig 2. Dose response in broilers to Na-butyrate supplementation (Nollet et al., 2004).



Most of these data were obtained in humans or laboratory animals with some confirmation in swine (e.g. Kotunia et al., 2004). In avian species these functions of butyrate await confirmation. Clearly, on the basis of the functions listed above butyrate contributes to the accelerated development of healthier intestines. As a matter of fact the results of Leeson et al (2005) in broilers seems to confirm this potential.

Fig 3. Effect of a 10-day post hatching lectin stress and 250 ppm Na-butyrate until day 21 on live weight and FCR in broilers. (Vandendriesche, 2006).



The effect of butyric acid on gut health and immune status was also tested through the use of a lectin-challenge model (Fig .3. - Vandendriesche, 2006;). Lectin stress was induced through the inclusion of 7.5 % of kidney beans in the diet during the first 10 days. Lectins from kidney beans are known to have potent anti-nutritional properties which influence the structure and function of both enterocytes and lymphocytes (Cordain et al., 2000). Challenging broiler chicks with lectins during the first 10 days resulted in reduced weight throughout the 42 day feeding period and increased FCR following the stress period. The addition of butyrate corrected the negative effect of lectins to the levels of weight gain and feed conversion of control animals. Thus the negative effects of lectins on enterocytes, gut health and immunity were reversed by supplying the SCFA butyrate at a level of 250 ppm. Since butyrate was only supplied during the starter and grower phase the stimulatory effect of butyrate was permanent.

Conclusion.

A wide range of feed additives are available for poultry diets however research on the use of these additives to stimulate enteric development is limited. Key to the early establishment of a functional digestive system is the supply of nutrients that stimulate the enterocytes and intestinal micro-structures. SCFAs, in particular butyrate, play an important role in regulating the developing intestinal environment. They also serve as nutrients or stimulatory intermediates for the enterocytes. Butyrate and other SCFAs can be supplied through the feed, the drinking water or through the stimulation of specific intestinal microbial population. Results with supplementation of SCFA, especially butyrate, indicate however, that under current production conditions butyrate production by indigenous microbes is insufficient. Stimulation and maintenance of a specific, viable microbiota may be an important step in the supply of selected SCFA. Probiotics can play a role in directing the composition of the intestinal microbiota. However, the use of specific prebiotics that selectively stimulate the indigenous microbes are considered more effective in terms of production responses as well as towards the production of SCFAs. Since the intricate interactions between the substrate (diet), the microbiota and the host animal are still inadequately understood the direct use of additives such as organic acids in feed or drinking water remains for the moment the most efficient means to stimulate enteric development.

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