Recent Advances in Animal Feed Additives such as Metabolic Modifiers, Antimicrobial Agents, Probiotics, Enzymes and Highly Available Minerals[a] - Review -

C. Wenk*
Institute of Animal Sciences, Nutrition Biology, ETH Zurich, Switzerland

ABSTRACT : Animal feed additives are used worldwide for many different reasons. Some help to cover the needs of essential nutrients and others to increase growth performance, feed intake and therefore optimize feed utilization. They can positively effect technological properties and product quality. The health status of animals with a high growth performance is a predominant argument in the choice of feed additives. In many countries the use of feed additives is more and more questioned by the consumers: substances such as antibiotics and β-agonists with expected high risks are banned in animal diets. Therefore, the feed industry is highly interested in valuable alternatives which could be accepted by the consumers. Probiotics, prebiotics, enzymes and highly available minerals as well as herbs can be seen as alternatives to metabolic modifiers and antibiotics. (*Asian-Aus. J. Anim. Sci. 2000. Vol. 13, No. 1 : 86-95*)

Key Words : Monogastric Farm Animals, Feed Additives, Antibiotics, Probiotics, Prebiotics, Enzymes

INTRODUCTION : FEED ADDITIVES IN VIEW OF THE CONSUMER TODAY

The various ways in which human food is produced are intensively discussed and questioned in modern societies. We expect food from plants, farm animals and microorganisms to be inexpensive, healthy and of good quality. Because the costs of environmental care are becoming highly significant, consumers, the food industry and politicians are increasingly concerned about environmental matters and low energy input. In addition, arguments come primarily from biological farming organizations and consumers organizations. In general, all of us expect our food to be as natural as possible and free of any toxic or undesired substances.

In highly developed countries we do not always feel the impact of the steady growth of world population. In twenty five years from now there will be almost 9 billion inhabitants (FAOSTAT, 1998) on earth who expect to get enough food to meet their nutritional needs. Today, more than 800 million people suffer from hunger. The goal to produce sufficient food for everybody can only be achieved if the world food production increases by about 2% per year. Furthermore, the actual world cereal reserves can supply current needs for less than two months, which is the lowest reserve of the last 20 years (FAO, 1996).

It is expected that world animal production will follow this trend. According to Han (1998) world production will grow 1.8 and 2.0% for pigs and chicken, respectively in the next 20 years. For beef production a slight reduction of 0.4% is expected mainly in developed countries.

In many parts of the world environmental pollution, available water resources, soil structure and energy availability are the primary limiting factors for increasing agricultural production. Therefore, world food production must grow without increasing the environmental waste load. This precondition demands the efficient use of all available resources of traditional and modern technologies!

There is no doubt that today's worldwide agriculture productivity must be increased. However, the consumers in highly developed countries make higher and higher demands on quality and idealistic images of food that focus attention on issues other than yield. The use of new technologies such as genetic engineering in food and animal feed production are questioned. Even synthetic amino acids, vitamins or other feed additives produced by modern technologies are banned in certain production systems.

A general ban of antibiotics as feed additives in animal nutrition is realized since 1986 in Sweden and is generally discussed in Europe because of the increased occurrence of pathogens resistant against therapeutical antibiotics used in animals and humans. This effect is somehow brought in connection with the use of antibiotic feed additives as growth promoters in farm animals. Despite the report of the SCAN (1996) showing no evidence that the use of avoparcin has lead to increased resistance against vancomycin (an antibiotic used in human medicine), avoparcin was banned as growth promoter in the European Union in April 1997. After an intensive discussion of these decisions Switzerland banned all antimicrobial feed additives as performance promoters in 1999. Only

* Address reprint request to C. Wenk. Tel: +41-1-632-3255, Fax: +41-12-632-1128, E-mail: caspar.wenk@inw.agrl.ethz.ch.
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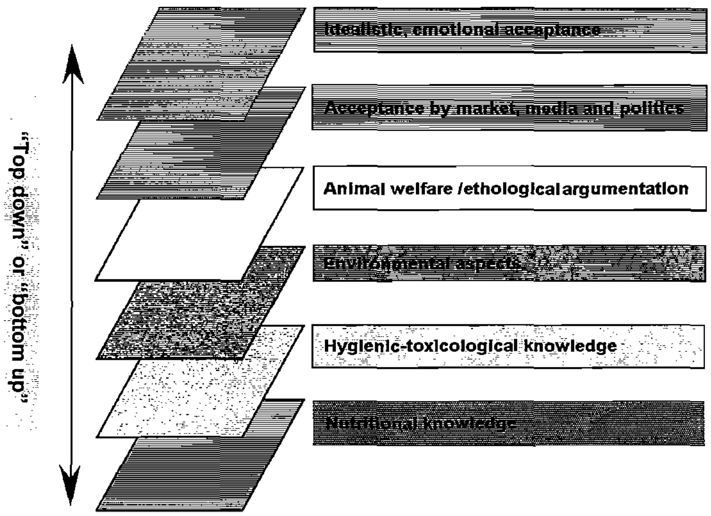


Figure 1. Decision making processes when evaluating a food

arecoccidiostats permitted in poultry feeds. The European Union has banned in the mean time tylosin phosphate, virginiamycin, Zn bacitracine and spiramycine. A further law banned the use of olaquindox and carbadox as feed additives for 1999.

We are well aware that nutrition policy decisions are strongly influenced by idealistic and emotional arguments conveyed by media and politicians who lack sufficient scientific knowledge in animal production and environmental considerations. Scientists in nutrition, hygiene, toxicology or ecology try to explain phenomena or calculate the benefits and risks of nutritional variables by first understanding fundamental physiological facts involved. They see nutrition clearly from the "bottom up-view", as shown in figure 1.

The end consumer (whoever it is) with an idealistic and emotional view of nutrition, selects food based on what he believes to be as natural as possible and the best for him. In addition to experience and expectations he builds his opinion mainly on the basis of advertisements or product appearance. During recent years politicians, media and food distributors have stimulated wide-ranging debates on food and human nutrition. In contrary to the scientific approach, they look at issues from the "top down" perspective (figure 1). Problems arise due to these different points of view because frequently the consumer with the "top down-view" and the scientist with the "bottom up-view" do not speak the same *"language"* and therefore do not respect the considerations and arguments of each other.

GOOD AND SAFE FOOD FROM ANIMAL ORIGIN

As explained earlier, the quality of food from animal origin is determined by many different criteria. In modern human nutrition we are defining new categories of food and pharmaceuticals. Special properties of food in the context of health have led to terms such as functional foods [FUFOSE (Functional Food Science in Europe): 'A *functional food* contains a food component (whether a nutrient or not) which affects one or more targeted functions in the body in a positive way. This also includes foods in which a potentially harmful component has (or components have) been removed by technological means.], health foods or nutraceuticals. They play increasingly an important role in Japan, in the United States and in many other developed countries. In table 1 the most important arguments for food quality are summarized.

Table 1. The determinants of food quality

- Nutrient content
- Health and hygienic aspects
- Taste
- Ecological aspects
- Animal welfare aspects
- Origin of animals
- Image of food (especially meat)
- Price

In the "bottom-up" view nutrient content, hygiene and health along with taste are the main determinants of animal products. In the "top down" view image and origin of the products are of major importance. However, the final decision to purchase a product is often based on price. The ecological value is often based on origin but instead should be expressed as a scientific value based on energy input/output and pollution. In most cases, an objective determination of the ecological costs is missing. Therefore, new criteria have to be formulated, which are generally relevant and can be accepted by both scientific and consumer perspectives.

FOOD PRODUCTION AND ENVIRONMENTAL ASPECTS

In the discussion of the environmental impact of animal production the principal aspects of the nutrient cycles are often not properly considered. In many cases the extensifying of animal production is in many cases believed to be the only way to reduce pollution. On the other hand interest exists in making animal production highly efficient. That typically means more units of output per unit of input. In intensive agriculture production systems the main goal is to maximize the yield per area, which in most cases has the effect to minimize the nutrient losses during production (Wenk, 1996). One main argument to intensify production is therefore the reduction of nutrient losses. However, the benefits of increased production intensity must be balanced against an environmental burden when intensity of animal production is considered. There must be a reasonable relation between the number of farm animals and area available so that excrements can be efficiently used in the nutrient cycles and inevitable losses such as methane, ammonia or other metabolic gases do not overload the environmental capacities.

The major arguments for an efficient animal production with a reduced environmental load in animal production are listed in table 2.

Table 2. Animal nutrition and the environment: How can we increase efficiency and reduce environmental load per unit of product?

- Healthy animals
- Higher performance
- Increased feed conversion ratio
- Better nutrient availability
- More home-grown feedstuffs
- More by-products from food industry

Healthy animals are the first requirement for a successful, environmentally friendly animal production. Furthermore, the overall performance can be increased by improving fertility and health. The feed conversion ratio can be heightened by using more available nutrients or by a change in protein and fat deposition in growth. For instance, protein deposition requires about four to six times less energy input than fat deposition.

Feed additives can be used to increase the health status, fertility and performance of farm animals. They improve the feed conversion ratio mainly by regulating feed intake and increasing digestibility of nutrients and energy. Better nutrient availability can be achieved by supplying highly available forms of nutrients (e.g. mineral proteinates) or with the use of special feed additives that increase nutrient digestibility. Enzymes, antimicrobials and probiotics can have a very positive effect on nutrient utilization when used with appropriate feed ingredients.

A major contributor towards higher nutrient utilization and reduced environmental load is the use of home grown feedstuffs and by-products from food industry. With these groups of feedstuffs we help to establish closed nutrient cycles on farms and/or regional areas. Since home grown feedstuffs often contain a high fiber content, the supplementation of the diets with a combination of enzymes (carbohydrases, proteases, lipases or phytases) helps to improve the feeding value, particularly for monogastric animals with a limited digestion capacity.

With the expected restricted use or ban of dietary antimicrobial agents, (at least in special production programs), we must explore new ways to improve and protect the health status of farm animals, to guarantee animal performance and to increase nutrient availability. This goal can be attained by good housing or climate conditions as well as by the best possible combination of the so-called pronutrients (Rosen, 1996) available including pro- or prebiotics, organic acids, dietary fibers, highly available nutrients or eventually herbs. He defined the pronutrients as "microfeedingstuff used orally in a relatively small amount to improve the intrinsic value of the nutrient mix in an animal diet".

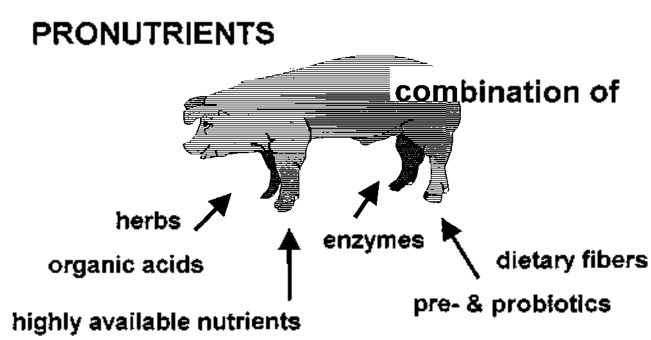


Figure 2. Pronutrients instead of antimicrobials?

Feed additives as an alternative to antibiotics act in many different ways to influence health status and/or nutrient availability. Such pronutrients develop the main activity in the digestive tract. For instance, organic acids help to improve digestive processes especially in monogastric animals. With improved pH regulation, the colonization of undesirable micro- -organisms in the upper digestive tract can be prevented. Enzymes are used mainly for monogastric species to increase nutrient availability. Carbohydrases help to alleviate negative effects of dietary fibers. Enzymes allow the use of by-products of the food industry and/or of home grown feeds with reduced risk of digestive problems. Proteases in optimal combination with carbohydrates increase the digestion processes especially of legumes like soybeans or lupines. Yeast cultures can stimulate microbial activity in ruminants (rumen) and horses (caecum) and help to optimize the digestion processes. Enterococci and lactobacilli are mainly used in pigs and poultry. They stimulate and stabilize the digestion processes and help to increase competitive exclusion of undesirable microorganisms in the digestive tract. The main consequence of this feed supplementation is improved nutrient utilization and nutrient supply of the animals.

A wide range of other substances are increasingly used to optimize digestive processes and to improve the health of the animals. Oligosaccharides can selectively influence the microflora by enhancing competitive exclusion or by supplying specific nutrients (Gibson and Roberfroid, 1995). Herbs may affect feed intake, flavour, product quality through pigmentation, the digestion through certain antimicrobial effects or through a reduction of the oxidation of unsaturated fatty acids in the digestive tract.

FEED ADDITIVES AND WHY THEY ARE USED IN ANIMAL PRODUCTION

The use of feed additives in animal production is subjected to governmental regulations in most countries. The following list of the different categories corresponds to legislation of the European Union and Switzerland. The registered products in the different categories can be different between countries.

Table 3. List of categories of permitted feed additives in animal nutrition in Europe (Switzerland: regulation of 1.4.95; similar regulation for EU)

A performance promoters (antibiotics, others; banned since 1.1.1999)
B substances with antioxidative effects
C flavours and substances affecting food intake
D coccidiostats
E emulsifiers, stabilizers (e.g. organic acids) etc.
F coloring substances
G preservatives
H vitamins, provitamins etc.
I trace elements
J binding substances etc.
K probiotics
L enzyme mixtures

In contrast to other countries, in Europe metabolic modifiers are not permitted as feed additives for any farm animals. Despite the ban, β-agonists or other similar substances are used illegally. Since many hormones cannot be used legally as feed additives in the EU they are not dicussed here together with the β-agonists.

The registration of feed additives is based on three different arguments. The claimed effects of a product on the farm animals (performance, disease prevention, antioxidant effect, pigmentation etc.) must be clearly demonstrated by experiments and the absence of undesired side effects has to be well documented. Furthermore safety for man, animal and environment must be guaranteed.

ANTIMICROBIAL AGENTS

Antimicrobial agents that are used as feed additives develop their activity in the digestive tract (mainly small intestine). They exclude competitively undesired microorganisms that utilize desired nutrients and produce undesired or toxic substances. The consequence is an optimal environment for the intestinal mucosa, which allows an efficient nutrient absorption (François and Michel, 1968). Therefore nutrient utilization, feed conversion ratio, and growth rate are in most cases increased. Furthermore, the health status of animals that are kept improperly is better. With dietary supplementation of antibiotics to healthy piglets even under good housing and hygienic conditions an increase of body weight gain and of the feed conversion ratio of 10 to 15% can be expected (Wenk, 1995). The effect of antibiotics is pronounced in young growing animals especially under unfavourable climatic and management conditions. With increasing body weight that beneficial effect is reduced and can often not be observed in the finishing period. Pfirter et al. (1998) estimated the effect of the withdrawal of antibiotics as performance promoters on growth performance and feed conversion efficiency of different growing farm animals as follows:

Table 4. Effect of the withdrawal of antibiotics as performance promoters on growth performance and feed conversion efficiency in different growing farm animals

	Reduction of daily body mass gain	Increase of feed per gain
Veal calve production	7-8%	4-5%
Beef production	4%	2%
Weaned piglets	8%	5%
Growing pigs	5%	3%
Fattening pigs	2%	1%
Pig production	5%	2%
Growing chicken	3%	2%

In Europe the available antimicrobial substances are clearly separated into a subgroup for use as feed additives as well as a subgroup for therapeutic application. The available knowledge on resistance transfer between antibiotics led several times to an update of the list of antibiotics used in agriculture. Recently avoparcin was banned because a resistance transfer with vancomycin or other glycopeptid antibiotics used in human medicine could not be excluded. Recently the European Union banned also carbadox and olaquindox. Under the pressure of consumer organizations and supermarkets the complete ban of all antimicrobial performance promoters in farm animals is discussed intensively. Though the risk of antimicrobial resistance transfer from feed additives for farm animals toward human use is not yet epidemiologically confirmed (SCAN, 1996; Bager, 1997), the highest risks are caused by the application and misuse of therapeutic antibiotics in humans. The utilization of antibiotics as feed additives or as medical supplements cannot be differentiated with a high accuracy. Furthermore, the risks of antibiotics applied in the medical care of pets are not known.

The consequence of the ban of antibiotics as growth promoters in farm animals could led to a misuse of other substances with an efficient antimicrobial effect such as Zn or Cu in high concentrations. The ecological consequences of such a misuse can be enormous.

PROBIOTICS AND PREBIOTICS

Many microorganisms are used in the form of pro- or prebiotics in animal nutrition. For instance, lactic acid bacteria are applied for silage fermentation, other microorganisms serve as protein sources or are utilized to produce amino acids, vitamins, highly available minerals etc.

With the increasing ban of antimicrobial feed additives, lactobacilli (for monogastric animals) and yeast cultures (for ruminants or horses) are employed more and more as "**probiotics**". These are by definition *microbial food / feed supplements that beneficially affect the host by improving its intestinal microbial balance* (Gibson and Roberfroid, 1995).

A new concept is the use of oligosaccharides derived from bacterial or yeast cultures such as fructose-, mannanoligosaccharides or other oligomers. Again, these additives help to improve the digestion capacity and increase the health status of the animals. These substances are generally called "**prebiotics**". The definition is based on their physiological function:

Nondigestive food / feed ingredients that beneficially affect the host by selectively stimulating the growth and/or activity of one or a limited number of bacterial species already resident in the digestive tract and thus attempt to improve host health.

A main aspect of the use of prebiotics in diets for young animals is the beneficial effect on the competitive exclusion of pathogenic microorganisms like salmonella (Savage and Zakrzewska, 1995; Spring, 1996). Prebiotics can also be specific nutrient sources for beneficial microorganisms like fructose-oligosaccharides for *bifidobacterium spp.* (Bornet et al., 1994; Rochat et al., 1994).

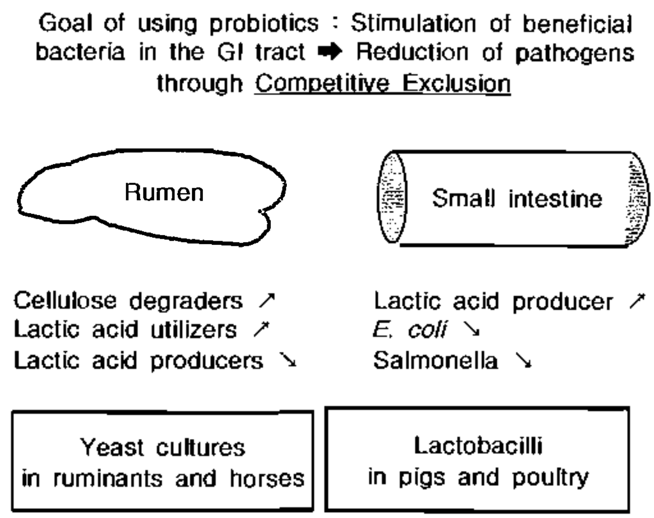


Figure 3. How probiotics can have a beneficial effect in animal nutrition

Effective probiotics on the one hand are stimulating beneficial microorganisms in the gastrointestinal tract and on the other hand suppress pathogens by competitive exclusion. In ruminants for instance, yeast cultures stimulate the growth of cellulose degraders and lactic acid utilizers in the rumen (Dawson et al., 1990). That optimal pH regulation can, as a consequence, suppress lactic acid producers.

In monogastric animals a low pH in the upper small intestine helps to suppress pathogens like *E. coli* or salmonella. Therefore probiotics for monogastrics should stimulate lactic acid producers. Wenk (1990) observed in experiments with pigs and chickens not only an increased growth rate and better feed efficiency after the supplementation of high fiber diets with lactobacilli and yeast cultures, but also a higher digestibility of energy and of some fiber fractions.

ENZYMES

Biotechnologically produced exogenous enzymes are available to enhance digestive capacity especially of young or ill animals as well as to increase the digestibility of the feed. A variety of carbohydrases are employed to enhance digestion of carbohydrates including resistant starch or dietary fibers (Annison and Choct, 1993; Chesson, 1987; Johnson et al., 1993;

Wenk, 1993). Proteases are available which increase the utilization of vegetal proteins such as soybeans or other legumes (Pugh and Charton, 1995; Schutte and de Jong, 1996) and also lipases (Pluske et al., 1997). Phytases which increase the digestibility and absorption of phosphorus and also of other minerals are in use especially in regions with a high animal production intensity to reduce environmental load (Pallauf et al., 1992; Jongbloed et al., 1993).

Exogenous enzymes can then be utilized successfully if they are well adapted to the secretion of endogenous enzymes and the microbial enzyme synthesis. This is of great importance especially in young, stressed or ill animals. In older animals the choice of exogenous enzymes depends on the feed composition taking also into account the microbial enzyme synthesis (figure 4).

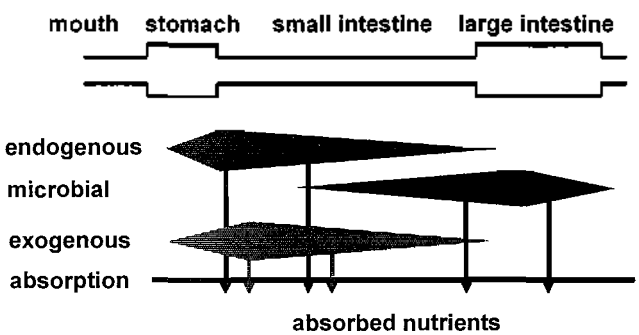


Figure 4. Competition between enzymes in the digestive tract

Enzymes that increase generally the utilization of organic matter and energy have always a beneficial effect on feed conversion ratio and also an improving effect on environmental aspects. Phytases or proteases that increase the availability of nitrogen, phosphorus or other minerals can only develop their positive effect on environment if the nutrient supply is reduced according to the increased availability.

The use of by-products in animal nutrition is very relevant to the Swiss and other European feed industries. In Switzerland about 60% of pig feed consists of locally produced by-products and only about 40% of the feed derives from directly grown raw materials. In poultry diets only around 30% of by products are used as feedstuffs (Wenk, 1995). An optimal nutrient utilization can be achieved by combining adequate exogenous enzymes and by-products. These days most chicken diets in intensive production systems contain carbohydrases to achieve a better nutrient utilization and to diminish digestion problems due to a reduced viscosity in the digesta. In piglet diets carbohydrases and eventually other enzymes are used to optimize the digestion processes of endogenous enzymes (Lindemann et al., 1986; Inborr, 1994).

In sustainable agriculture the use of homegrown feedstuffs is the most efficient means of nutrient utilization, thus promoting nutrient recycling in a closed system. In Switzerland whole maize is used as a major component of diets for ruminants. The latter can also be fed to growing-finishing pigs or to pregnant sows, if the feeding value of whole maize plants can be increased by an adequate enzyme mixture.

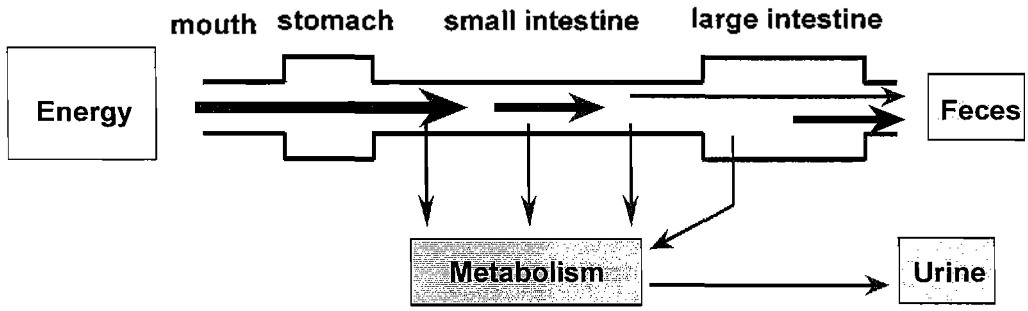
In a trial three different enzymes were added to a feed with 50% maize plants to see whether the feeding value of the whole diet could be increased. Even though the maize plant produces a high amount of bio-mass, it is rich in fiber. The energy utilization of the test diet with 50% maize plants was increased with one enzyme by 4%, and energy digestibility of maize plants alone was increased by about 10%. The energy content of the whole diet could be increased by adding feed enzymes from below 12 up to 13 MJ digestible energy per kg DM (Wenk et al., 1993).

Studies conducted in Sri Lanka on pigs fed with swill and rice bran diets have shown positive responses to carbohydrases and antibiotics (Samarasinghe, 1995). Though the enzyme alone resulted in a small increase in body weight gain, the addition of both enzyme and antibiotic increased the weight gain by about 25%. Obviously there was a very distinct positive interaction of the enzyme and antibiotic. Birzer et al. (1991), Vukic Vranjes and Wenk (1995) and Wenk et al. (1997) showed in their studies at least an additive effect of the two supplements.

HIGHLY AVAILABLE MINERALS

Highly available trace minerals such as chelates or proteinates can replace those inorganic sources currently in use to meet the nutrient requirements of farm animals. Often a better health status or increased performance can be observed. Due to the higher bioavailability the use of organic trace elements allows the reduction in total nutrient content in the diet. A reduction in the environmental load is the consequence.

Organic chromium in the form of the biologically available glucose tolerance factor supports the carbohydrate metabolism and the action of insulin. Although affecting several physiological mechanisms only the chromium's effect on insulin action seems to be clearly understood. Recent research gave evidence that the binding of Cr at an oligopeptide, named low-molecular weight chromium binding substance, is responsible for potentiation of insulin's action (Davis and Vincent, 1997). However, partly connected with the insulin metabolism special interest was focused on Cr as carcass modifier since supplementation of dietary Cr decreased fat and increased protein accretion in



better digestibility of:	corresponds to:
org. matter & energy	less environmental load
N, P & other nutrients	less environmental load if reduced content in the feed

Figure 5. Better digestibility of nutrients due to the use of enzymes: Consequences for environment

pigs (Lindemann, 1996; Mooney and Cromwell, 1995, 1997) and poultry (Hossain, 1998). In addition several studies reported beneficial effects in stressed animals due to dietary Cr (Chang and Mowat, 1992; Moonsie-Shageer and Mowat, 1993).

The copper-lysine complex (Coffey et al., 1994), chelated iron and zinc proteinate (Wedekind et al., 1994) are further examples of the application of organic trace elements with a beneficial effect on the health of young and high yielding monogastric animals.

The trace element selenium (Mahan, 1995) when provided as Se-yeast can have specific effects on metabolism and therefore help to increase health status of the animal. Mahan (1999) observed an increase of this trace element in products of animal origin (meat and eggs) if it was fed as Se-methionine instead of an inorganic form. Selenium is a limiting trace element in human nutrition in many countries worldwide. Furthermore food from animal origin is an important Se-source (Zimmerli et al., 1998). Therefore the increase of the selenium content of these products must be appreciated in the sense of the idea of functional food.

METABOLIC MODIFIERS

In growing farm animals metabolic modifiers are used to have a better partition of the energy deposition for growth in form of protein and fat. β-agonists have a high potential for increased protein deposition and simultaneously a reduced fat deposition (Buttary and Dawson, 1987). The results of various experiments in growing animals indicate that the energy utilization is not more efficient but the anabolic effect on protein deposition is compensated by a reduced fat deposition. Undesirable effects of β-agonists on heart rhythm and stress as well as the fears of carcinogenic side effects of β-agonists are the main reason of todays ban of these substances.

FEED ADDITIVES AND ENVIRONMENT

The majority of the discussed feed additives have a beneficial effect on the digestive processes and allow a more efficient use of the nutrients. There are two different modes of action that are described in figure 5.

The increase in energy and organic matter digestibility by supplementing diets with enzymes, antimicrobial agents, pre- or probiotics, can reduce the environmental load due to a decrease in faeces excretion. With single nutrients such as nitrogen and minerals (P, Zn, Cu, etc.) a reduced excretion can only be achieved by enhancing the digestibility of that nutrient and at the same time reducing the nutrient content in the diet. Therefore, the use of highly available minerals and specific feed enzymes like phytase is ecologically sound if these factors are taken into consideration.

CONCLUSIONS

The beneficial effect on health status, growth performance as well as nutrient and energy utilization are mainly the reasons, why animal feed additives such as metabolic modifiers, antimicrobial agents, probiotics, enzymes and highly available minerals are

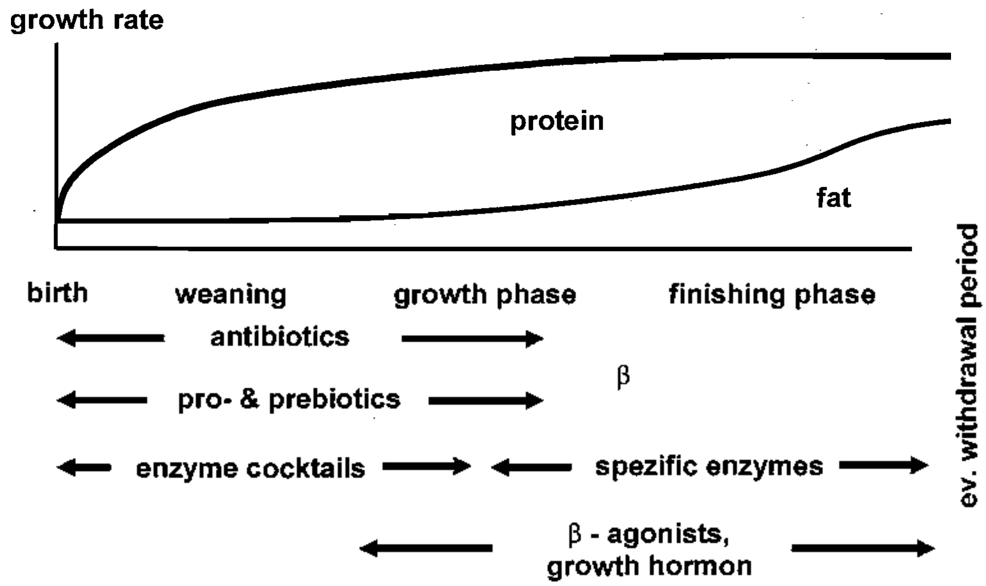


Figure 6. Optimal use of feed additives in growing animals such as pigs or chickens

Table 5. Main modes of actions of feed additives in growing animals

	Digest./ absorpt.	Benefic. MO	Path. Mo	Metabolic changes	
				Nutrient deposition	Intermed. partion
Antibiotics	++	+	++	+	(+)
β-agonists	(+)	-	-	(+)	++
Probiotics	++	++	+	+	-
Prebiotics	(+)	++	++	+	-
Enzymes	++	+	+	+	-
Dig. minerals	++	-	-	-	(+)

++: significant, (+): possible, +: existing, -: doubtful.

widely used. Although β-agonists are not registered in most countries they are used occasionally as partitioning agent in growing animals. With the trend towards more natural animal production systems, antimicrobial agents are also banned by special label programs or at the national level (e.g. Sweden). Discussions about the possibility of the transfer of resistance against antibiotics from animal products to humans fortify that development. Therefore agriculture is looking for more friendly supplements to the consumer. Whether pro- or prebiotics, enzymes, herbs, highly available minerals or other feed additives are appropriate has to be considered in each practical application. Only the best combination of the possible alternatives can be recommended.

Metabolic modifiers, antimicrobial agents, pro- and prebiotics show the best activity in young animals when the digestive system is still in development. While metabolic modifiers are influencing the intermediate metabolism antimicrobial agents, pro- and prebiotics affect the digestive processes in different modes of action. They can partly replace each other. Enzymes increase the digestion capacity in young animals and help to decrease the risk of digestive problems and therefore increase the health status. In older animals enzymes can be used successfully to increase the use of (homegrown) feedstuffs rich in dietary fibers or other nutrients with a low digestibility and to reduce environmental load with nutrients.

The modes of action of the feed additives discussed before can be summarized as follows (table 5).

Most feed additives discussed develop their activity in the digestive tract or have a special form that allows a high availability (organic minerals). A higher absorption rate of the nutrients and changes in the microflora are the consequences. Furthermore nutrient and energy requirements are covered efficiently. This increases the health status and performance of the animals.

With the ban of antibiotics in Europe and eventually soon also in other countries strategies of alternatives are often discussed. They are of main interest in veal calve production and in young pigs. The strategies must be based primarily on optimal management and housing conditions. The main aspects are:

- adapted temperature (microclimate of the calves and piglets)
- fresh air, no draft
- adapted space and appropriate floor
- if possible straw bedding
- low humidity and minimal dust
- good rotation system

The nutrition of the animals must primarily focus that the animals are supplied with all essential nutrients and energy in adequate amounts. In big groups adequate feeding troughs must allow that all animals can get sufficient amounts of food. On the other hand overeating of the heavier animals should be avoided so that digestive disorders do not occur. With the following measures the risks digestion problems mainly in the young pig can be minimized:

- low acid binding capacity
  - reduced mineral content (< 6 g Ca and < 5 g P per kg feed)
  - reduced protein content (but essential amino acids according to requirement)
  - use of organic acids (mainly fumaric and lactic acid)
- use of enzymes, prebiotics and dietary fibers
  - use of mainly phytases and carbohydrases
  - use of fructose and mannose oligosaccharides
  - use of pectins or other soluble dietary fibers
- liquid feeding systems with the possibility of fermentation before feeding
- use of herbs, botanicals, spices or essential oils
- use of probiotics (lactobacilli)
- supply of sufficient amounts of special amino acids (glutamine and alanin)
- avoidance of anti-nutritional factors (ANF)

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