Chapter 20
Phytogenic Feed Additives in Animal Nutrition

Tobias Steiner and Basharat Syed

Abstract Antibiotic growth promoters (AGPs) were – and in many countries are still – continually included in animal diets in sub-therapeutic concentrations in order to achieve better feed conversion and higher growth rates by reducing the activity of the microbiota in the digestive tract. However, the routine use of AGPs in animal diets was associated with the development of bacterial resistance towards several antibiotic substances. While scientists continue their research on the actual impact of the extensive use of AGPs in animal feeds on microbial resistance in humans, consumers are becoming increasingly aware of the negative effects of the so-called "superbugs" (bacteria highly resistant to antibiotics).

A complete ban of AGPs was implemented in Europe in 2006 as a consequence of growing public concern. In the meantime, the ban of AGPs has become a worldwide trend where many countries outside the European Union are on their way towards restricting or banning the use of AGPs in animal feed. However, solutions are not only sought to replace AGPs in animal feeds, but also to reduce the overall use of veterinary antibiotics in animal agriculture. Thus, current research is directed towards measures to help animals maintain good health and reach their growth potential.

The feed industry has recognized the potential of plant-derived substances for different animal species in the last few years. Phytogenic feed additives (PFAs) referring to essential oils, spices, herbs or plant extracts, combine bioactive ingredients and flavouring substances. Hence they are categorised as 'sensory additives' according to European legislation. PFAs improve growth rate, nutrient digestibility and gut health in animals. These properties of PFAs project them as a suitable alternative to AGPs in animal production.

Keywords Phytogenic feed additives • Growth promoters • Performance • Animal nutrition • Antibiotic resistance

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1 Introduction

Global meat production has been increasing steadily over the last decades. Considering a steady growth in the human population, this trend is projected to continue into the near future (FAO 2012). Thus, modern animal agriculture relies on efficient production techniques in order to supply high-quality, safe animal products in a sustainable way while maintaining profitability for producers. An increasing demand for animal protein on the one hand, and stricter regulations in terms of animal welfare and environmental protection on the other, make further improvements in current production techniques mandatory. In particular, feed conversion, calculated as the amount of feed consumed per unit of live weight gain, eggs or milk production, is a key parameter that needs to be further improved in the coming decades. The contribution of feed cost to overall production cost is 60–70 %. Thus, optimizing the utilization of feed is key to sustainable and profitable animal production. The animal requires a certain level of nutrients to meet its requirement for metabolic processes such as basic body functions and the accretion of muscle tissue, or the production of eggs or milk. In most parts of the world, energy, protein and phosphorus are the most expensive feed ingredients. It is, therefore, mandatory to utilize them in the most efficient way possible in order to optimize feed efficiency.

Antibiotic growth promoters (AGPs) were – and in many countries still are – continually included in animal diets in sub-therapeutic concentrations in order to achieve better feed conversion and higher growth rates by reducing the activity of the microbiota in the digestive tract (Dibner and Richards 2005). However, the routine use of AGPs in animal diets was associated with the development of bacterial resistance towards several antibiotic substances (DANMAP 2011; Marshall and Levy 2011). While scientists continue their research on the actual impact of the extensive use of AGPs in animal feeds on microbial resistance in humans, consumers are becoming increasingly aware of the negative effects of the so-called "superbugs" (bacteria highly resistant to antibiotics). A complete ban of AGPs was implemented in Europe in 2006 as a consequence of growing public concern. In the meantime, the ban of AGPs has become a worldwide trend where many countries outside the European Union are on their way towards restricting or banning the use of AGPs in animal feed. In 2011, for example, Korea banned the use of AGPs in animal feed. However, solutions are not only sought to replace AGPs in animal feeds, but also to reduce the overall use of veterinary antibiotics in animal agriculture. Thus, current research is directed towards measures to help animals maintain good health and reach their growth potential.

An increasing number of reports have confirmed that supplementation of diets with plant-based, i.e. phytogenic feed additives (PFAs) resulted in improved zootechnical and animal health parameters, hence indicating the potential of PFAs in animal nutrition.

2 Current Use of Phytogenic Feed Additives

The feed industry has recognized the potential of plant-derived substances for different animal species in the last few years. Thus, PFAs are used to an increasing extent, mainly in feeding programs for swine and poultry. Commercial products that are available in the market today differ substantially with regards to the ingredients, physical appearance and level of complexity in their formulations. Products include simple formulations based on a single (e.g. oregano or thyme oil) or few raw materials as well as highly complex formulations utilizing a large number of ingredients. Phytogenic substances utilised in PFAs include herbs, spices, essential oils and non-volatile extracts, from, for example, clove, anise, thyme, fennel or melissa, and many others (Table 20.1) (Máthé 2007).

PFAs are either applied in solid powdered, granulated or liquid forms. Solid PFAs are usually incorporated in premixtures or complete feeds. Recent developments include encapsulation techniques that aim to protect the active substances against thermal impacts, mask their strong odours or delay their release in the digestive tract. Liquid PFAs are suitable for drinking water or milk replacer supplementation, as well as for spray application to hydro-thermally processed feed, such as pelleted or extruded diets.

The fine art of formulating PFAs lies in a suitable combination of plant materials. This requires a deep understanding of (1) the flavouring properties, as well as (2) the biological effects of plant compounds in the animal organism. The combination of different plant materials allows for utilising a wider range of properties that plants offer. It is assumed that an interaction of all constituents will work harmoniously together, making a well-formulated PFA more potent than the sum of its individual parts.

Table 20.1 Herbs and parts thereof used in feed additives

Common name	Latin name	Parts utilised[a]
Anise	*Pimpinella anisum*	Seeds
Caraway	*Carum carvi*	Seeds
Cinnamon	*Cinnamomum verum*	Bark
Chamomile	*Matricaria recutita*	Flowers
Citrus	*Citrus sp.*	Peel
Clove	*Syzygium aromaticum*	Buds
Fennel	*Foeniculum vulgare*	Seeds
Garlic	*Allium sativum*	Bulb
Ginger	*Zingiber officinale*	Rhizome
Melissa	*Melissa officinalis*	Leaves
Onion	*Allium cepa*	Bulbs
Oregano	*Origanum vulgare*	Leaves
Peppermint	*Mentha piperita*	Leaves
Rosemary	*Rosmarinus officinalis*	Laeves
Sage	*Salvia officinalis*	Leaves
Thyme	*Thymus vulgaris*	Leaves
Valerian	*Valeriana officinalis*	Root, rhizome

[a]Parts either used in complete, ground form or to obtain extracts

3 Mechanisms of Action of Phytogenic Feed Additives in Animals

Phytogenic compounds have a complex mode of action, a fact which has been a big myth even for those using these substances as additives in animal feed. Therefore, a major objective of research and development in the last few years was to understand the role of PFAs in improving animal performance and health (Hippenstiel et al. 2011; Windisch et al. 2008; Máthé 2009). However, the vast number of phytogenic compounds and differences in the composition of PFAs that were used in the various studies make it difficult to postulate a general mode of action that is applicable to all commercial PFAs in the market.

In fact, the effectiveness of plant active ingredients has often been underestimated in recent years and it is not seldom that their mode of action has been misunderstood even by companies offering such products. It is often postulated that PFAs are anti-microbial. Indeed, many secondary plant ingredients and extracts do have such properties. The in vitro anti-microbial activity of plants and plant ingredients is well documented through scientific findings (Helander et al. 1998; Ultee et al. 2002; Burt 2004; Nikaido 2003; Preuss et al. 2005; Ouwehand et al. 2010) and plants themselves can respond to bacterial or viral attack for example by producing "phytoalexins" (Ahuja et al. 2012). The focus on anti-microbial effects is largely driven by the argument that PFAs are substitutes for AGPs. However, it would be inappropriate to limit the value of phytogenic substances in animal nutrition to an anti-microbial effect only.

Recently, more scientific data has been generated, which enables us to better understand the effects that PFAs have in the animal. The possible effects of PFAs are summarised in Fig. 20.1. With regards to an improvement in feed conversion, increased digestibility is considered a main effect of PFAs. Parameters influenced by PFAs include the secretion of digestive juices and enzymes, a modulation of the immune system, changes in the intestinal morphology, improvements in nutrient utilization and consequently, a higher level of performance. However, the above-mentioned parameters are interrelated with each other. Positive effects of PFAs on the morphology of the small intestinal tissues, for example, are postulated to increase nutrient digestibility. Furthermore, a stabilization of the intestinal microbiota results in reduced levels of microbial metabolites in the digestive tract, hence relieving the immune system and increasing energy available for muscle accretion.

4 Flavouring Effects of Phytogenic Feed Additives

Food preferences and food choices are influenced by food flavour (Clark 1998). Flavour is largely perceived through taste (gustation) and smell (olfaction). Describing how food tastes, human beings practically speak about the food flavour,

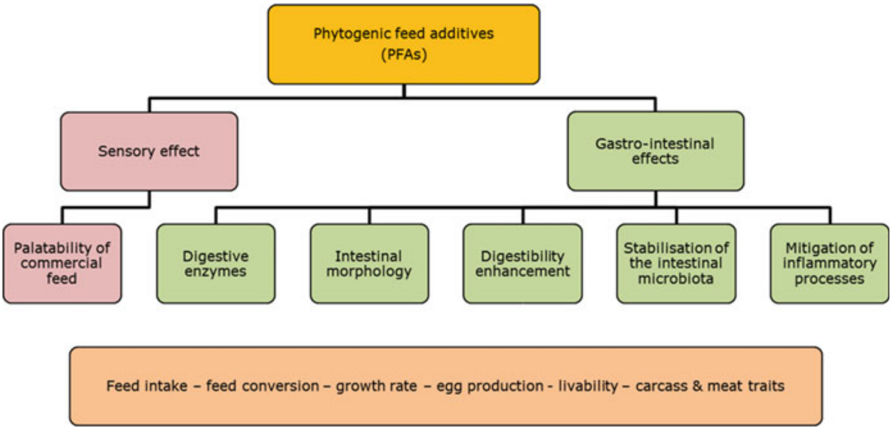

Fig. 20.1 Phytogenic compounds are effective at different levels in the digestive tract

but not the basic tastes like sour, sweet, bitter or salty. The texture and temperature of foods and the chemical burn of chili peppers and other irritants is also detected in the oral cavity. Taste receptors located in the oral cavity, particularly on the tongue, are responsible for perceiving the basic tastes. As confirmed by Drewnowski et al. (2002), components of flavour (such as the aroma of vanilla or orange), are airborne particles which enter the nose from the back of the mouth through the so-called retro-nasal transport or directly through the nasal passage. Since the sensation aroused by umami compounds such as the amino acid glutamate (often in the form of the sodium salt monosodium glutamate) occurring naturally in foods and providing flavour to many foods and cuisines around the world, is distinct from the other four taste qualities, scientists count its perception as a fifth basic taste quality (Beauchamp 2009).

In a scientific study, Bach et al. (2012) reported that lambs were able to sense the crude protein content in their diets and were accordingly able to modulate the short-term consumption of flavoured feeds based on their nutrient requirement.

Animals, particularly young piglets at the time of weaning, usually show insufficient feed intake, thus resulting in suboptimal growth performance. Among other factors, voluntary feed intake of young piglets and other animals is influenced by taste and olfaction. Therefore, animal nutritionists aim to provide highly palatable diets by including pleasant flavours. However, meaningful choice tests investigating the preference for certain flavours are scarce, indicating a certain preference for sweet, fruity and milky flavours in piglets (Jacela et al. 2010; Nofre et al. 2002; McLaughlin et al. 1983).

There are several types of flavours which can be added to feed to enhance or mask the natural flavour characteristics of feed and thus improve its palatability. However, there are differences between animal species, pigs and cattle being much more sensitive to taste compared with poultry (Chamorro et al. 1993; Ganchrow and Ganchrow 1987; Davies et al. 1979). Plant ingredients, such as herbs, spices, their extracts or single active principles, have pronounced flavouring properties. Their inclusion in diets, therefore, influences the sensory properties of these diets. Consequently, these compounds are authorized as flavouring substances in the European Union (Regulation EC No. 1831/2003).

5 Effects of Phytogenic Feed Additives on Digestibility

Digestibility refers to the extent to which nutrients contained in a diet are absorbed by an animal's body as it passes through the animal's digestive tract. Better digestibility of nutrients, or simply, better digestion, contributes to better feed efficiency. Poor digestibility of a diet is not only visible in sub-optimal feed efficiency, but also by the negative effects that impact the digestive tract directly. It is assumed that low digestibility of the diet is reflected in greater amounts of undigested feed in the gut, which is potentially subject to fermentation by the intestinal microbiota. Microbial fermentation takes place mainly in the large intestine, but also, to a lesser degree, in the small intestine. The presence of undigested nitrogenous compounds (i.e. proteins, amino acids) favours the formation of undesired metabolites, such as ammonia and biogenic amines. These metabolites are adverse not only because of their toxicity, but also because they are produced by decarboxylation of dietary essential amino acids (Kroismayr et al. 2008a). For example, cadaverine is made from lysine. Consequently, intestinal imbalances occur, resulting in enhanced inflammatory processes and accelerated turnover of the intestinal tissue, which results in poorer performance and potentially diarrhoea.

Improvements in digestibility were reported for different nutrients and amino acids in pigs (Maenner et al. 2011; Kong et al. 2009) and poultry (e.g. Mountzouris et al. 2011; Amad et al. 2011). Figures 20.2 and 20.3 indicate significant improvements in protein and amino acid digestibility, measured at the terminal ileum of weaning pigs (Maenner et al. 2011).

In another study with weaning piglets, PFA (oregano, anise and citrus essential oils) supplementation improved protein and organic matter digestibility (Zitterl-Eglseer et al. 2008). This was in concert with a reduction in the concentrations of aerobic and anaerobic bacteria in the gastrointestinal tract (Kroismayr et al. 2008a), which consequently indicates that the competition for nutrients between the host animal and its intestinal microbiota was decreased when the PFA was fed. Furthermore, intestinal concentrations of undesired microbial metabolites (i.e. ammonia and biogenic amines) were decreased in response to the PFA, which resulted in a relief from intestinal challenges, a stabilization of the digestive tract and ultimately, an improvement in weight gain, feed intake and feed conversion. Improvements in nitrogen digestibility were reported in pigs fed an essential oils mixture (rosemary, cinnamon, thyme, oregano and clove) at 5 and 7, but not at 9 weeks of age (Huang et al. 2010), indicating an influence of age.

Among other factors that will be discussed in the following sections, increased digestibility may be due to enhanced secretions of saliva, bile acids and digestive

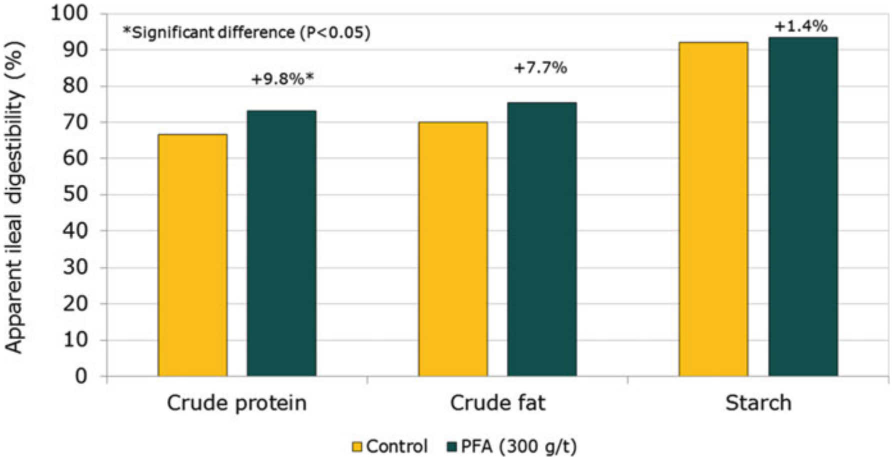

Fig. 20.2 Effect of a phytogenic feed additive on apparent ileal digestibility of crude protein, crude fat and starch in weaned piglets (Adapted from Maenner et al. 2011)

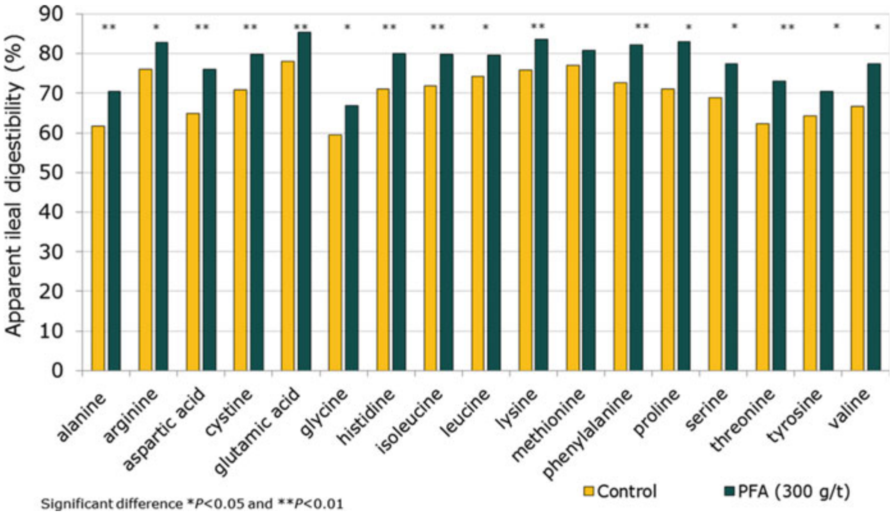

Fig. 20.3 Effect of a phytogenic feed additive on apparent ileal digestibility of amino acids in weaned piglets (Adapted from Maenner et al. 2011)

enzymes. However, studies investigating these effects are rather scarce, with a few examples in rats (Rao et al. 2003; Platel and Srinivaran 2000a, b, 2004) and broilers (Jang et al. 2004; Lee et al. 2003).

6 Anti-inflammatory and Anti-oxidative Effects of Phytogenic Feed Additives

It is well documented that infections lead to inflammation, hence the release of pro-inflammatory cytokines, chemokines and adhesion molecules (Collins et al. 1995). Therefore, restricting inflammation is of prime importance for proper animal health and growth. Cytokines not only activate immune cells, but also have an intense and deteriorating influence on animal health by reducing feed intake and promoting muscle tissue catabolism (Johnson and Escobar 2005).

The frequency and occurrence of inflammatory processes as a result of infections or feed-dependent changes are inversely proportional to animal health and growth performance, as outlined by Niewold (2007). The largely infamous metabolic inflammation as a consequence of feed intake is a normal physiological response of the intestines. Metabolic inflammation is influenced by specific feed constituents and is related directly to the energy value and the glycemic index of the feed consumed (Margioris 2009). In order to maintain the physiological coherence of the animal body, metabolic inflammation is firmly managed and systematised in the animal organism. In this way, the animal organism profits from a down-regulation of the intestinal inflammatory responses. However, in high producing commercial livestock, in spite of the firm physiological control of metabolic inflammation, the regulatory mechanism can be disturbed e.g. by large amounts of high-energy feed. Since phytogenic compounds have pronounced anti-inflammatory properties, this underlines the potential of PFAs to down-regulate inflammatory processes in the digestive tract.

The anti-inflammatory effects of phytogenic compounds were elucidated in a number of studies (Miguel 2010; Kroismayr et al. 2008b; Gbenou et al. 2013). The direct anti-inflammatory activity of a PFA (blend containing essential oils from peppermint, anise, clove and caraway) was examined at a cellular level in a test model with inflammation-induced intestinal cells (Gessner et al. 2013). Inflammation was induced by treating the cells with tumor necrosis factor α (TNFα). These cells were either incubated or not with an extract of the PFA. The first element to study was the nuclear factor κB (NF-κB), an important transcriptional factor that controls the expression of different genes [interleukin 8 (IL-8), intracellular adhesion molecule (ICAM-1) and monocyte chemotactic protein (MCT-1)] that are involved in the regulation of the pro-inflammatory response. The experiment revealed inhibitory effects of the PFA on IL-8, ICAM-1 and MCT-1 (Fig. 20.4). Thus, the PFA exerted a positive effect on the cellular inflammatory status by down regulation of NF-κB.

Protective effects of phytogenic compounds may also result from their anti-oxidative properties. Anti-oxidative effects were reported for a large number of plant substances (e.g. Miguel 2010; Wei and Shibamoto 2007). In this context, an important cellular element is the transcription factor Nrf2. Activation of the Nrf2 pathway leads to the induction of genes responsible for cellular defence against reactive oxygen species and detoxification of xenobiotics. The above mentioned

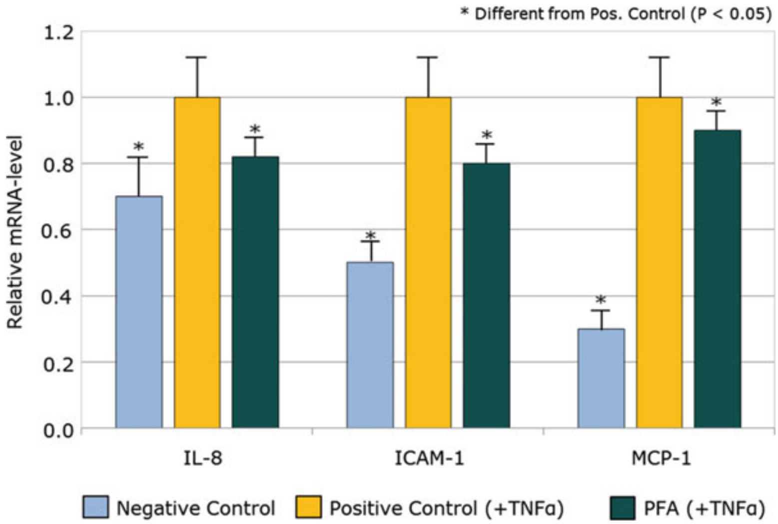

Fig. 20.4 Anti-inflammatory effect of a PFA (down-regulation of NF-κB target genes) (According to Gessner et al. 2013)

PFA was found to up-regulate Nrf2 target genes, i.e. cytochrome P450 isoform 1A1 (CYP1A1), heme oxygenase-1 (HO-1) and UDP glucuronosyltransferase isoform 1A1 (UGT1A1) (Gessner et al. 2013), hence providing further evidence for the protective effects of phytogenic compounds at the cellular level (Fig. 20.5). Therefore, regular supplementation of PFAs in the diet may act as prophylactic agents inflammatory reactions in the gastrointestinal tract by inhibiting the NF-κB pathway and stimulating the anti-oxidative factor Nrf2.

These findings are supported by experiments of Mueller et al. (2012), who examined the influence of different phytogenic substances (broccoli, turmeric, oregano, thyme, rosemary) on the regulation of xenobiotic- and antioxidant enzymes in the intestine and the liver of broilers. The authors found an up-regulation of the ‘antioxidant response element’ (ARE) genes in the small intestine, indicating reduced oxidative stress in the organism.

7 Effects of Phytogenic Feed Additives on the Intestinal Microbiota

An imbalance in the animal’s gastro intestinal microbiota due to dietary or environmental changes is damaging for the growth, health and feed conversion of the animal. In contrast, an ideal, stabilized microbiota allows optimum growth performance (Schaedler 1973). As reviewed by Windisch et al. (2008), literature depicting the anti-microbial role of PFAs is ample. In in vitro studies, components derived from thyme and oregano plants, namely thymol and carvacrol, as well as

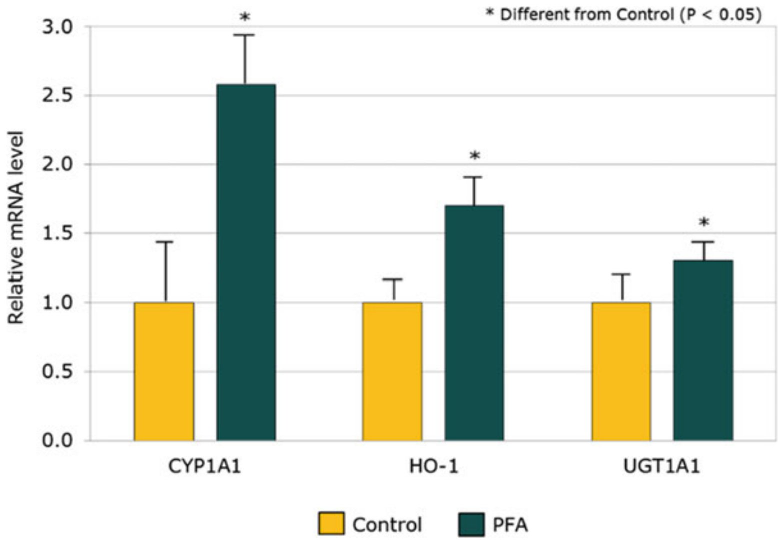

Fig. 20.5 Anti-oxidative effect of a PFA (up-regulation of Nrf-2 target genes) (According to Gessner et al. 2013)

many other compounds, demonstrated anti-microbial activities. Helander et al. (1998) reported that the effect is attributed to the lipophilic character of the active principles of phytogenic compounds, which permeate the cell membranes and mitochondria of the microorganisms, and inhibit the energy metabolism and the membrane-bound electron flow, leading to a collapse of the proton pump and draining of the ATP pool. The denaturation of cytoplasmic proteins and lysis of the cell membranes have also been attributed to high concentrations of essential oils.

The application of PFAs as alternatives to AGPs in livestock feeding seems logical because of their proven anti-microbial activity in vitro. Therefore, the intake of PFAs in animal feed is expected to influence the population as well as the composition of the gastrointestinal microbiota.

There is an increasing trend regarding in vivo studies on the influence of PFAs of the gut microbiota; however, the results are hard to correlate and interpret because of the diverse methodology employed during the investigations. Although methods to determine the activity vary, an impact on microbial communities can be tested in all parts of the intestinal tract. Some studies in broilers demonstrated a clear reduction of pathogenic bacteria such as *Escherichia coli* and *Clostridium perfringens* (McReynolds et al. 2009; Mitsch et al. 2004; Jamroz et al. 2005) and these effects are attributed mainly to their phenolic components and their action on microbial cells (Burt 2004; Si et al. 2006).

An anti-microbial effect of PFAs, however, is sometimes not observed in feeding trials, which may be due to optimal housing and hygienic conditions or the use of highly digestible diets (Hippenstiel et al. 2011). Taking into account that the dosages of PFAs in animal diets are usually lower than effective anti-microbial concentrations determined in vitro (Franz et al. 2010), a stabilising effect of PFAs on the gut microbiota is more likely than a direct bactericidal effect.

Indeed, it was shown that PFAs facilitate the proliferation of bacteria that are generally considered as beneficial, such as *Lactobacillus* (Mitsch et al. 2004; Jamroz et al. 2005; Mountzouris et al. 2011). Mountzouris et al. (2011) observed that inclusion levels of a PFA of 125 and 250 mg/kg diet resulted in a purportedly beneficial modulation of the caecal microbiota. There was a linear increase of caecal *Lactobacillus*, *Bifidobacterium* and Gram-positive cocci concentration with increasing PFA levels in 42 day-old broilers. In addition, caecal coliforms at 14 days of age were significantly lower at the inclusion levels of 125 and 250 mg/kg diet compared with the AGP Avilamycin. It is plausible that due to the reduction of undesired bacteria, including Clostridia, coliforms, Staphylococci and others, more space is available for lactobacilli to grow. Once the lactobacilli are established, they might selectively exclude pathogens from colonisation due to the fast proliferation, colonization and possibly acidification in the gut (McReynolds et al. 2009).

The inhibitory effect of PFAs on *Clostridium* is encouraging and paves the way for the removal of AGPs from diets. Clostridia, particularly *C. perfringens*, are responsible for necrotic enteritis in poultry although in the normal intestinal microbiota, *Clostridium* is detected irregularly and in small numbers (Barnes et al. 1972). Phytogenic compounds also inhibited the growth of clostridia in vitro (Briozzo et al. 1988; Dorman and Deans 2000). Mitsch et al. (2004) opined that PFAs stabilize the gut microbiota and thereby reduce the colonization of clostridia in the gut.

In a series of infection experiments in which broilers were orally challenged with *Clostridium perfringens*, birds fed a PFA (blend of essential oils from oregano, anise and citrus) showed less clinical signs of necrotic enteritis (i.e. reduced severity of necrotic lesions, lower levels of *C. perfringens* in the small intestine and lower mortality) compared to challenged, non-supplemented birds (McReynolds et al. 2009). Similar conclusions were drawn by Engberg et al. (2012). The authors carried out two experiments, in which the influence of increasing dietary concentrations of dried *Artemisia annua* leaves and n-hexane extract from fresh *A. annua* leaves on broiler performance was investigated. The results indicated that the extracts derived from *A. annua* could modulate the course of necrotic enteritis and compensate to a certain extent for disease-associated weight losses.

Numerous studies investigated the potential of phytogenic substances to prevent coccidiosis (Reisinger et al. 2011; Naidoo et al. 2008; Giannenas et al. 2004), one of the most costly diseases in commercial poultry caused by protozoan infections and currently controlled mainly by the routine use of anticoccidial drugs in the feed. Reisinger et al. (2011) observed that dietary supplementation with an essential oil-based PFA increased villus length and goblet cell density in the mid-ileum part of the small intestine of broilers exposed to a mild coccidial vaccine challenge. The authors concluded that PFA supplementation may have created an improved barrier against pathogens during this coccidial exposure. Alp et al. (2012), in a study designed to evaluate the effect of dietary oregano essential oil on performance, carcass yield, and serum IgG levels of broilers, concluded that the additive may provide an alternative to conventional anticoccidial additives in broiler feeds. A complete replacement of anticoccidial drugs, however, in the near future seems rather unlikely because of the lack of long-term, large-scale studies investigating the efficacy of PFAs for sustainable coccidiosis prevention.

8 Effects of Phytogenic Feed Additives on Intestinal Morphology

Morphological changes in the gastrointestinal tissues caused by PFAs may provide further information on possible benefits to the digestive tract. In general, PFAs caused an increase in height of villi across the small intestine in poultry (Hong et al. 2012; Reisinger et al. 2011; Peric et al. 2010). Similar effects of a PFA were reported by Namkung et al. (2004) in studies with pigs. This ought to increase the absorptive surface area and efficiency of digestion and absorption of nutrients. Greater villus height may also increase the activities of enzymes secreted from the tips of the villi, contributing to improved digestibility (Baurhoo et al. 2007).

An improved barrier function through higher numbers of goblet cells, as reported by Reisinger et al. (2011) is supported by Tsirtsikos et al. (2012) who carried out studies in which the duodenal mucus layer thickness of broilers showed a pattern of linear increase with increasing dietary PFA concentrations. Similar observations were reported by Jamroz et al. (2006), confirming the potential positive effect of PFAs on intestinal morphology.

9 Effects of Phytogenic Feed Additives on Animal Performance

Effects of PFAs on zootechnical parameters result from the mechanisms of action discussed in the above sections. In general, animal performance, e.g. body weight gain, feed conversion ratio and feed intake are influenced by several factors, namely genotype, feed composition, feeding systems, management, housing, environmental and hygienic conditions. The positive influence of PFAs on zootechnical parameters has been confirmed in a number of studies. An approximately 15 % improvement in body weight gain against a control group was observed by Çiftçi et al. (2005) in broilers. Mohamed and Abbas (2009) also recorded a 6 % increase in body weight gain in broilers by supplementing the diets with 1 g fennel per kg of diet. Nevertheless, certain studies have also depicted a negative influence of the phytogenic compounds on body weight gain. Cross et al. (2003) reported a tangible decrease in body weight gain when 5 g/kg thyme essential oil was added to the chicken feed. However, Cross et al. (2007), supplementing chicken diets with 1 g essential oil of thyme per kg, recorded a significant improvement in body weight gain. Similarly, Toghyani et al. (2010) reported an approximately 6 % improvement in body weight gain by supplementing broiler diets with 5 g thyme per kg of diet. Simsek et al. (2007) reported significant improvements in body weight, carcass characteristics and organoleptic analysis of meat in broilers by feeding 400 mg of anise essential oil per kg of diet.

A 5 % improvement in body weight was attributed to a favourable shift in intestinal microbiota by Tiihonen et al. (2010) in broiler chickens by supplementing the diets with a mixture of 15 mg thymol and 5 mg of cinnamaldehyde per kg of diet. A blend of essential oil from oregano, clove and anise improved the FCR in broilers by around 12 % against the control group and 8 % against a group of birds supplemented with AGPs (Ertas et al. 2005). Similarly, a 5 % improvement in FCR against the control group was recorded also by Ulfah (2006) by feeding broilers with a combination of the essential oils of oregano, thyme, cinnamon and eucalyptus. Hong et al. (2012) and Mountzouris et al. (2011) observed a 6 % and 7 % improvement in feed conversion, respectively, of broilers fed a blended PFA containing oregano, citrus and anise essential oils.

Similar results were obtained in studies with pigs. Supplementation of piglet diets with PFAs improved feed conversion by 3–5 % (Li et al. 2012; Maenner et al. 2011; Sulabo et al. 2007). Increased weight gain of piglets fed phytogenic compounds was also reported in different studies, as reviewed by Franz et al. (2010).

Improved feed conversion was reported in Holstein bull calves (Miller et al. 2012) when a blended PFA was included in the milk replacer. In addition, the authors also indicated reduced scour scores and fewer scour days.

10 Environmental Emissions

Among gases, ammonia is a concern in animal production because it negatively affects animal health and welfare. Furthermore, ammonia and odour emissions from animal production units in general are undesirable for people living close to farms. It is assumed that improvements in protein digestibility will result in better utilization of dietary amino acids, hence reducing the excretion of nitrogenous compounds in the slurry. As such, PFAs have the potential to reduce emissions from animal production units. Experiments investigating the influence of feed additives on gas emissions are rather scarce. In fact, such studies require strict experimental conditions, especially in terms of housing, temperature control, ventilation rates and measurements of aerial gas concentrations. Zentner et al. (2012), for example, reported a 24 % reduction in aerial ammonia concentrations in growing-finishing pigs fed a PFA based on oregano, thyme, anise and citrus essential oils. Furthermore, the authors found a reduction in odour emission, measured in odour units per cubic meter, by 29 %, indicating a close correlation between these parameters.

El-Deek et al. (2012), investigating the effects of feeding two levels of dietary crude protein (21 % vs. 23 %) in combination with or without two levels of green tea (1.5 and 3 g/kg diet) or one level of oxytetracycline at 0.1 g/kg diet, reported that decreasing the dietary crude protein level to 21 % had no adverse effects on the growth rate of broilers. Green tea supplementation at 1.5 g/kg diet increased growth rate and improved FCR by 10 %. The authors concluded that feeding broiler chickens a 21 % protein diet containing adequate amino acid levels when supplemented with green tea, had no negative effects on productive performance. This may contribute to decreased environmental pollution by decreased nitrogen excretion.

11 Effects of Phytogenic Additives on Meat Traits

Successful marketing of any food depends on the sensory characteristic of the product. In the marketing of meat, tenderness and succulence of the meat are of high importance. Unfortunately, the meat processor has only a limited influence on these factors. Therefore, knowledge about the possibilities of optimising the primary production of the meat on the farm is important for the food industry.

The potential efficacy of PFAs to improve overall meat quality attributes such as carcass yield, dressing percentage, fillet and tender yield, organoleptic cooked meat parameters, and the overall palatability and acceptability of meat is another area of scientific research. In a scientific study to investigate the potential of essential oils as growth promoting agents and as potential alternatives to AGPs with regards to carcass traits in broilers, Hong et al. (2012) observed that breast meat was more tender and thigh meat was juicier for birds in the essential oil group compared to the control and AGP groups.

Javan et al. (2012) evaluated the effect of dietary essential oil (*Zataria multiflora*) supplementation on the microbial growth and lipid peroxidation of broiler breast fillets during refrigerated storage. It was concluded that the essential oil delayed the peroxidation and microbial spoilage of chicken breast fillets. Similar results were reported for chicken meat (Avila-Ramos et al. 2012; Spernakova et al. 2007; Young et al. 2003; Botsoglou et al. 2002), turkey meat (Govaris et al. 2007) and fish (Giannenas et al. 2012) using different aromatic plants. In contrast, Simitzis et al. (2010) did not observe an influence of oregano oil on meat traits in finishing pigs, which may be attributed to the limited experimental duration of only 35 days.

Beneficial effects of dietary supplementation with PFAs on meat quality traits are mainly attributed to the anti-oxidative properties of phytogenic compounds. Supplementation of diets for Rainbow trout with either a carvacrol- or a thymol-based PFA significantly decreased malondialdehyde formation in the fillets, indicating enhanced oxidative stability of the fillet. In addition, glutathione-based

Table 20.2 Effect of PFAs on the antioxidant status of trout fillet after feeding the experimental diets for 8 weeks (antioxidant status was assessed during refrigerated storage at 0 or 5 days) (Adapted from Giannenas et al. 2012)

	Day (0)	Day (5)
Malondialdehyde (nmol/mg protein)		
Control	34.1[a]	49.1[#, b]
PFA-C	32.4[a]	38.6[#, b]
PFA-T	30.2	32.3[*]
Glutathione-S-transferase (mmol/min/mg protein)		
Control	2.12[#, a]	1.28[#, b]
PFA-C	2.82[*, a]	1.89[#, b]
PFA-T	2.84[*, a]	2.39[*, b]
Glutathione reductase (U/mg protein)		
Control	27.1[#, a]	16.6[#, b]
PFA-C	30.1[#, a]	21.4[*, b]
PFA-T	35.2[*, a]	24.5[*, b]

Phyto-C PFA based on carvacrol, *Phyto-T* PFA based on thymol
[*, #]Values in the same column with a different superscript symbol differ significantly ($p \leq 0.05$)
[a, b]Values in the same row with a different superscript letter differ significantly ($p \leq 0.05$)

enzyme activity at 0 and 5 days of storage was higher in fillets from both PFA-supplemented groups compared to the control, as shown in Table 20.2.

12 Future Considerations and Conclusions

The level of standardisation of PFAs has increased over the last 10 years. However, the different additives available in the market vary greatly in their composition, and thus in their in vivo effects as well. There are an increasing number of in vivo studies which focus on different aspects of incorporating PFAs in animal diets. Although, the results of these studies vary to a certain extent, positive results predominate in the conclusions.

Improvements were observed in the majority of the investigations to evaluate the influence of PFAs on digestibility, morphology of and inflammatory processes in the digestive tract, as well as modulation of the intestinal microbiota and, finally, the impact of PFAs on zootechnical parameters.

Despite a large number of scientific as well as field studies on the influence of PFAs on animal health and performance, the exact mode of action of these feed additives remains to be further elucidated. Aspects like undesired effects and effects of over-dosage need to be further investigated in both in vitro and in vivo trials to ensure the safe and productive use of PFAs.

An important aspect of future research should be to conduct standardised trials indicating the composition of the PFAs employed in the investigation, so that the observations could be easily compared. Potential synergistic effects of phytogenic compounds are likely; however, this needs to be studied in more detail and under standardised conditions.

Based on the literature available to date, PFAs comprising of single or combinations of components have significant potential to be considered as alternatives to AGPs. This is of increasing importance in view of the global trend to restrict or reduce the overall use of AGPs and antimicrobials in animal production.

Furthermore, the main focus of future considerations regarding the use of PFAs in the commercial livestock industry should be aimed at addressing the following issues necessary for sustainable animal production:

- Production efficiency: To organize a timely animal production that maintains profitability along the food chain.
- Animal health and welfare: To improve animal health, while reducing the use of therapeutic antibiotics.
- Consumer safety: To reduce the risk of bacterial resistance and with that, achieve a higher level of consumer security.
- Public acceptance: To improve the prestige and trust in commercial animal production utilizing plant-derived products.
- Sustainability: To conserve resources (protein, phosphorus, water and others) through improved feed efficiency.
- Environmental protection: Improving feed conversion and hence preventing environmental pollution with a simultaneous improvement in performance.

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