RESEARCHREPORT
ANIMAL SCIENCE

Title: Critical Review of Acidifiers **– NPB #05-169**

Investigator: James E. Pettigrew

Institution: University of Illinois

Date Submitted: September 29, 2006

Abstract:

We have reviewed the scientific literature on the use of acids in pig diets for the purpose of improving pig health and productive performance. Our focus is on effects of acids on growth performance and some associated factors (independent variables) on the response to acids. The independent variables include diet type, dietary inclusion level of acid, type of acid, weaning age, and performance level. We address both the proposed mechanisms of action of acids and the empirical data on practical results. In this study we have mostly focused on responses to organic acids because they are the most commonly studied acidifiers in pig diets, but the effects of inorganic acids on pig performance are also mentioned when appropriate.

Acid products significantly increase growth rate of pigs, on average more than 12.0% and 6.0% for 0-2 and 0-4 week post-weaning periods, respectively. The addition of acids to the diet also improves the performance of growing (3.5%) and finishing pigs (2.7%). Under stressful or disease conditions, acids appear to be an effective measure to reduce scouring rate and mortality and to sustain a good growth performance. The response of growth performance to acids is not remarkably influenced by type of diet, inclusion level of acid, weaning age or performance level or their interactions. Diet acidification decreases the pH value of the diet, but the data do not suggest it decreases the pH value of the gastrointestinal digesta. In addition, the current data have shown that addition of acids to the diet greatly enhances the dry matter digestibility (0.82%), the response of which to acids is appreciably altered by diet type, acid type, and acid level. It is also indicated that acids differently affect the microbial populations along the digestive tract and they do not produce an environment that is favorable for potentially beneficial bacteria like *Lactobacillus* but adverse to coliforms and *E.coli*. In summary, the application of acids to pig diets can bring benefits to the pork production industry and is likely to be a promising alternative to the use of growth promoters. The improvement in nutrient digestibility and the changes in microbial population are the important influences probably caused by acids.

Introduction:

The Non-Antimicrobial Production Enhancers (NAPES) Committee of the National Pork Board believes that there is a substantial amount of information on the use of acid products for pigs in the literature that can be very useful if reviewed critically and thoroughly to summarize the existing knowledge. Thus, the NAPES Committee commissioned the critical review of the literature on acidifiers. This project focuses on the effects of acid products on growth performance, nutrient digestibility, microbial population, and pH value.

Objective:

To review critically the available information about the effects of organic and inorganic acids and their salts on the pig, its growth performance and health, and to draw conclusions useful to the pork production industry.

Materials & Methods:

We searched thoroughly the following bibliographic databases:

- PubMed
- Commonwealth Agricultural Bureaux International (CABI)
- Agricultural Online Access (AGRICOLA) database
- Journal of Animal Science
- Journal of Feed Science and Technology
- Canadian Journal of Animal Science
- Livestock Production Science
- Research in Veterinary Science
- Journal of Physiology and Animal Nutrition
- Journal of the Science of Food and Agriculture

We also looked for relevant websites and obtained appropriate papers cited in earlier reviews.

We summarized the results across experiments by meta-analyses, using the results cautiously.

Results:

Our complete review accompanies this report.

Discussion:

Thorough discussions of the results for acid products are included in the detailed review that accompanies this report.

Lay Interpretation:

The inclusion of various organic acids or their salts to diets improves the growth performance of pigs and helps in preventing scouring and high mortality post-weaning. The beneficial effects of organic acids on growth performance are evident within the first few weeks of weaning, and the influence gradually decreases as the pig grows old. Diet acidification significantly reduces the diet pH, but does not affect the gastrointestinal pH. The use of acids in diets for pigs enhances the nutrient digestibility and dissimilarly affects the microbial populations in different parts of the digestive tract.

A Critical Review of Acidifiers

C.M. Tung and J.E. Pettigrew

Department of Animal Sciences, University of Illinois

1. Introduction

Early weaning is widely practiced in many commercial farms throughout the world with the aim to increase sow productivity, i.e. increase in numbers of piglets/sow/year. However, when weaned at an early stage of 3 – 4 weeks old or earlier, piglets commonly have low feed intake, poor growth and diarrhea (Barnett *et al.*, 1989). It is believed that separating piglets from the sow at weaning causes a stressful situation to them while the piglets no longer benefit from the protective components of the sow's milk. In addition to the stress, immature development of the gastrointestinal tract of young pigs, exposure to new feedstuffs, and changes in the gut microflora lead to a higher risk of digestive disorders and diarrhea, particularly at the time of weaning (Shields *et al.*, 1980; Tang *et al.*, 1999; Burrin and Stoll, 2003). Antibiotics are frequently applied to weanling pigs' diets to overcome the post-weaning problems of weanling pigs.

In recent decades, acidifiers have been reported as potential alternatives, among other feed additives, to antibiotics in swine diets. Much of this interest arises from increased public awareness and objection to the use of antibiotics as growth promoters in animal diets. Some researchers have shown positive effects with dietary acidifiers in improving growth rate and feed efficiency (Burnell *et al.*, 1988, Giesting *et al.*, 1991, Eckel *et al.*, 1992, Boling *et al.*, 2000, Tsiloyiannis *et al.*, 2001a & b), but others have found nothing or negative responses (Radecki *et al.*, 1988, Eidelsburger *et al.*, 1992a, Manzanilla *et al.*, 2004). The inconsistent results and highly variable responses may be due to several factors such as stage of growth, complexity of diet, type of acid, inclusion level of acid, weaning age, and health status of pig. Therefore, the role of acids in improving growth performance has been controversial and the exact mode of action of acids remains unclear.

The objectives of this research project were to review critically the available information about the effects of organic and inorganic acids and their salts on the pig, its growth performance and health, and to draw conclusions useful to the pork production industry.

2. Procedures

In order to achieve our objectives, we have looked for information by using search engines (PubMed, CAB, Agricola) and related journals and proceedings. We have searched meticulously the Journal of Animal

Science, the Journal of Feed Science and Technology, Canadian Journal of Animal Science, Livestock Production Science, Research in Veterinary Science, the Journal of Physiology and Animal Nutrition, and the Journal of the Science of Food and Agriculture.

We undertook a comprehensive review and summary of all relevant studies on the topic. The conditions for including an experiment in our summaries were (i) the paper must have been subjected to peer review before publication, (ii) there had to be a clear comparison of the performance of pigs fed a diet containing acids to the performance of pigs fed a similar diet without acids, (iii) standard error of mean must be reported for use in our analysis, (iv) the experiment had to be concurrent, i.e., both treatments applied at the same time, and (v) for weanling pigs the weaning age was between 15 and 35 days. On the basis of these criteria we have gathered and summarized as complete a data set as possible. There are several reasons for doing so. First, any elimination of an experiment potentially generates a bias, so all data were included that meet the above five criteria. Second, the data set established is large enough to facilitate comparisons adequately.

We insisted that data be peer-reviewed for inclusion in our summaries, in order to provide confidence in the data. However, that policy has a cost. In a research area that is currently active such as this one, there are always important studies that have not yet been published in peer-reviewed journals, and our policy causes us to miss them. Perhaps more importantly, there is substantial commercial interest in acidifiers so there is likely much information that is held privately and unavailable to us or is available only in promotional literature. The overall result of these factors is that no review in such a field can be completely current, and this one is no exception.

Originally, the utilization of the absolute values of the performance data in the analysis was considered. However, a wide array of weaning weights and initial weights across experiments caused a broad range of performance values that would have placed undue weight on the experiments with higher values for performance variables. Therefore, except for pH values, the analysis was based on the percentage responses, i.e., the difference between acids and no acids performance values expressed as a percentage of the no acids value.

We performed meta-analysis on the data obtained, combining data from multiple experiments into a single statistical analysis. The experimental unit was the appropriate value from a single experiment. The data for each experiment was weighted by the inverse of the standard error of the treatment mean in that experiment to give greater weight to the more powerful experiments. For assessment of the practical response to acids, the response variables considered were average daily gain values during selected growth stages. For evaluation of proposed mechanisms of action, response variables were pH of diet or digesta (unweighted), and nutrient digestibility. The limited data on microbial populations in the digestive tract were evaluated less formally. For each response variable used in a meta-analysis, the dependent variable was the difference between the acid supplemented and control treatments. The data set was first analyzed to determine the overall response to acids. Then, except for pH values, analysis of variance was used to detect effects of several factors (independent variables) on the response to acids. The independent variables included diet type, dietary inclusion level of acid, type of acid, weaning age, and performance level. Interactions among the independent variables in response to acids were also statistically analyzed, but none were significant. The analysis was conducted through the proc GLM procedure of SAS (Version 9.1e; SAS Institute Inc., Cary, North Carolina), and least squares means were calculated. The differences among levels of an independent variable were considered significant when $p<0.05$.

The results of a meta-analysis depend entirely on the quality of the data set available for analysis. The regrettable tendency of some scientists and journals to decline to publish results that fail to show significant differences results in an unquantifiable bias in the literature, usually overestimating the value of technologies under consideration. Therefore, the analyses reported below probably overestimate the responses to dietary acidifiers. This problem occurs in any review of the published literature; the formal and quantitative analysis reported here only makes the underlying problem obvious.

3. Description of products

Acid products used in swine diets can be classified as organic acids and their sodium, potassium or calcium salts, inorganic acids, and blends of acids and salts. Some commercial products contain acids coated with lipid or other materials proposed to protect the acids from release in the upper part of digestive tract. The salt forms of acids are generally odorless and can be easily handled in the feed manufacturing process because of their solid and less volatile form. In addition, they are less corrosive and may be more soluble in water than the free acids. Inorganic acids recently used are hydrochloric, sulfuric and phosphoric acids. They are cheaper than organic acidifiers, but in pure state they are extremely corrosive and hazardous liquids. Combinations of acids are also added to pig diets, multiple kinds of organic acids or both organic acids and inorganic acids. In this study we have mostly focused on responses to organic acids because they are the most commonly studied acidifiers in pig diets.

4. Proposed/demonstrated mechanism of action

Several mechanisms through which dietary acids may produce desired effects have been proposed (Partanen, 2001); the following appear to be the most prominent:

- Reduced gastric pH
  - Reduced survival of pathogens through the stomach
  - Increased digestion of nutrients
- Direct killing of bacteria

The low pH of gastric contents is thought to kill many ingested bacteria. However, the gastric pH of the newly weaned piglet is notably higher than in the older pig, so in newly weaned pigs this protective action may be enhanced by any lowering of the gastric pH produced by acids in the feed.

A low pH is required for conversion of pepsinogen to pepsin, the active form of the most important gastric proteolytic enzyme. Separately, the pH activity profile of pepsin shows it to be most active at a low pH. Therefore, to the extent that dietary acids reduce gastric pH, they may also enhance digestion of protein, and perhaps other nutrients, especially in the newly weaned piglet.

Organic acids in undissociated form are lipophilic and can diffuse across bacterial cell membranes to reach the interior of the cell. There, in the relatively high intracellular pH, they dissociate and disrupt the bacterial cell function. The effect may be stronger in some bacteria than in others (Partanen, 2001).

The following paragraphs review the empirical data on key aspects of these proposed mechanisms.

4.1. Effects on pH value

The pH value of the diet used was appreciably reduced from 5.95 to 4.71 ($p<0.001$) when acid was added to the diet (Table 1). Still, our analysis revealed that addition of acid to the diet did not significantly ($P>0.05$) reduce the stomach pH (Table 1). The stomach pH value for the diets treated with acids was 3.66 while this figure for the control was 3.73. In addition, the stomach pH was lower with dietary acids than with the control diet in only 55% of the cases, higher in 36%, and in 9% of the cases the stomach pH was equal in the two treatments. This seemingly indicates that diet acidification is likely to have little influence on gastric pH.

Gastric contents are heterogeneous, and there is potential for markedly different pH values in different regions of the stomach. That heterogeneity introduces the possibility of difficult technical challenges in measurement of pH of gastric contents, and the details of those measurements are not always described in the published reports of the research. However, it is reasonable to assume that the measurement techniques were consistent within an experiment. The heterogeneity may have increased the variance of the measurements, but it is less likely to have introduced a treatment bias.

Diets with higher buffering capacity presumably provide a greater challenge to the acid secretory capacity of the pig and therefore increase the need for addition of acids to the diet. However, they also presumably reduce the impact of acids. Buffering capacity is higher in diets with higher concentrations of proteins and minerals, but we are not confident in our ability to predict buffering capacity quantitatively from the information provided in the research reports, so we have not estimated the impact of buffering capacity on the response to acids.

There are no obvious effects of acid type or level on the impacts on intestinal pH. In the pig's intestine, pH values of pigs fed acid-supplemented diets were generally higher than those of controls in research by Roth *et al.* (1992), lower in the work of Risley *et al.* (1991 & 1992) and Canibe *et al.* (2001), and inconsistent in the work of Eidelsburger *et al.* (1992b).

In summary, adding acid to the diet reduces the pH of the diet, but the data do not suggest it reduces the pH of the contents of the digestive tract. This observation casts doubt on some of the proposed mechanisms of action of acids.

4.2. Effects on Digestive Tract Microorganisms

Addition of organic acids to weaned pig diets has reportedly led to qualitative and quantitative changes of microbial population according to previous reviews (Ravindran and Kornegay, 1993; Roth and Kirchgessner, 1998). This phenomenon has been previously supposed to result from a low stomach pH capable of preventing the development of pathogenic bacteria and favorable to dietary protein digestion (Kirchgessner & Roth, 1982; Chapman, 1988; Koch, 2005). However, based on the available information, the effects of dietary acidifiers on gut microflora highly vary in different parts of the gastrointestinal tract.

Acids appear to increase numbers of coliforms and *E. coli* in the stomach (8 of 8 cases; Table 2) and have equivocal influences on them in the small intestine (Table 3) and cecum (Table 4). Conversely, the numbers of *Lactobacillus* (or *Lactobacillus* plus *Bifidobacteria*) were not clearly affected when measured in the stomach, but were usually reduced in the small intestine (22 of 27 cases; Table 3) and cecum (7 of 10 cases; Table 4). In the 6 cases in which both *Lactobacillus* and *Bifidobacteria* were counted, the acid treatments always had smaller values than the controls in both the cecum and colon. In the colon, numbers of both *Lactobacillus* and *E.coli* were lower (6 of 6 cases) when formic acid or its calcium salt was added to the diet. It is not clear whether this suggests that acids reduce total bacterial numbers in the large intestine. The results were more variable when other acids or their sodium salts were tested, but the salts were included in the diet at only 0.3%. We have not identified other relationships of acid type or level to the responses.

In brief, acids dissimilarly affect the microbial populations along the digestive tract. In the stomach, the numbers of coliforms and *E.coli* increase regardless of type and form of organic acid, but there is no clean-cut evidence about the effect of acidifiers on *Lactobacillus* population. Acids generally reduce the populations of *Lactobacillus* in the intestines and *E.coli* in the colon. It appears that addition of acidifiers to the diet may not result in an environment that is favorable for beneficial bacteria like *Lactobacillus* but adverse to coliforms and *E.coli*. The post-weaning growth lag phase in young pigs is an intricate and interrelated problem. It is important to determine what factors possibly produce a harmonized gut population of microorganism which would probably heighten nutrient utilization by piglets. Thus, the numbers and ratios of different bacteria species as well as factors involved should be taken into consideration in future studies. In summary, dietary acids appear to alter bacterial populations in the digestive tract, but the nature of the alteration needs further evaluation.

4.3. Improvement in nutrient digestibility

Acidifiers improve dry matter and crude protein digestibilities (Table 5). The current data indicate that the positive responses in dry matter and crude protein digestibilities are 0.82 and 1.33%, respectively ($p<0.05$). A review reported by Partanen and Mroz (1999) also confirmed improvements in the apparent total tract digestibility and retention of crude protein with acidification of diets for weaned piglets or fattening pigs. It is notable that the data we reviewed showed that acids clearly increase nutrient digestibility in the absence of a clear reduction in gastric pH. In fact, individual experiments (Eidelsburger *et al*., 1992c; Franco *et al*., 2005) found numerically greater digestibility with no reduction in gastric pH. This combination of results appears inconsistent with the proposal that increased nutrient digestibility results from reduced gastric pH, and raises the possibility that other mechanisms may be involved.

Diet type, acid type, and acid level significantly modify the response of digestibility to acidifiers (Tables 6 & 7). Diets formulated with plant and animal origin feed ingredients (1.14%) showed better response (P<0.05) in dry matter digestibility than those with only plant origin feed ingredients (0.32%). A greater improvement in dry matter digestibility was also demonstrated for formic acid (0.71%) than for fumaric acid (0.28%). This finding is in agreement with that reported by Partanen and Mroz (1999). Besides, the inclusion level of acid of more than 1.5% had far smaller positive response (0.48%) to acidifiers, compared to that of 1.5% or less (1.2%).

For crude protein digestibility, the diet type may alter the response of crude protein digestibility to acidifiers to some degree, even though no differences were statistically observed (P>0.05). The response value to diet with plant and animal origin feed ingredients (1.60%) was almost twice as much as that to diet with only plant origin feed ingredients (0.86%). Unlike the diet type, the acid type was recorded to be a significant contributor to the response of crude protein digestibility to acidifiers. Formic acid greatly improved crude protein digestibility by 1.64% while this figure was 0.57% for fumaric acid (P<0.05). In addition, there were no significant interactions among the above independent variables in responses of dry matter and crude protein digestibilities to acidifiers.

Generally, based on the available data, organic acids undoubtedly increase nutrient digestibility, especially crude protein digestibility. The response of digestibility to acidifiers varies widely depending on diet ingredients and type and level of acid utilized.

5. Growth enhancing influences

The inclusion of organic acid in feeds for pigs has been studied for decades with both negative and positive results. The magnitude of growth response is likely to be related to age (Table 8). The greatest improvement in performance is seen just after weaning and the effect diminishes as the pigs age. Our statistically analyzed result showed that mean improvements of growth rate were 12.25% and 6.03% for 0 – 2 and 0 – 4 week post-weaning periods, respectively (P<0.05). Similarly, addition of acids to diets improved (P<0.05), though to a lesser degree, the performance of growing (3.51%) and finishing pigs (2.69%). Apparently, acidifiers significantly promote the performance of pigs. The beneficial effects of organic acids on growth performance have also lately been confirmed in several reviews (Ravindran and Kornegay, 1993; Partanen and Mroz, 1999; Mroz, 2003).

The response also varies markedly within a certain stage of growth (Easter, 1988; Giesting *et al.*, 1991, Mroz, 2003). However, there were no significant effects of type of diet, inclusion level of acid, weaning age, or performance level or their interactions on the size of the response to acids (Tables 10, 11, & 12). This result suggests that the effect of acids on growth rate is robust, occurring across a wide range of conditions. It should be noted that none of the experimental diets fed in the studies summarized match those typically used now in commercial pork production in North America and many other part of the world.

Furthermore, it is revealed that as pigs grow older, there continues to be no effect of the previously mentioned factors on growth performance (Tables 11 & 12). In growing pigs, the response of growth performance to acidifiers was not significantly influenced by diet, type and level of acid, and performance level ($P>0.05$). Eidelsburger (1998) argues that as the piglets get older and the risk of digestive disorders decreases, the nutritional improvements that can be achieved decrease. There is no indication that the higher level of acid was more effective (1.91%) in growing pigs than the lower level of acid (5.35%). It is noted that formic acid and its salt in our dataset are the only acidifiers supplemented to the pig's diet during this stage of growth. As in the case of gastric pH, we have not estimated the impact of buffering capacity on the growth response to dietary acids.

Moreover, under stressful or disease challenge conditions, acidifiers seem to be a useful tool to overcome negative impacts such as increased diarrhea and high mortality (Appendix 12) and to maintain good growth performance (Table 9). This impact may become increasingly important if in-feed antibiotic use becomes increasingly restricted. The data indicate that pigs fed diet with supplementation of acidifiers performed remarkably better (9.35%) than the control ($P<0.05$).

Most previous studies have been conducted to evaluate the response of growth performance to organic acidifiers. The addition of organic acids to the diet has been demonstrated to be beneficial not only in early weaned pigs but also in growing and finishing ones. Due to the cost of organic acids and inconsistent results obtained, researchers have recently paid attention to use of inorganic acids for pigs in order to intensify the efficiency of acidifiers along the digestive tract with reasonable cost.

Inorganic acids added to the diet are hydrochloric, sulfuric, and phosphoric acids. It was found that growth performance was retarded with hydrochloric acid and sulfuric acid, but not with phosphoric acid (Giesting, 1986). However, Straw *et al.* (1991) indicated that supplementation of hydrochloric acid to the diet improved average daily gain during the first 3 weeks after weaning. Apart from the acidifying effect, hydrochloric acid is also utilized as a source of chloride to pig diets. Mahan *et al.* (1996 and 1999) showed that the improved performance and nitrogen retention, due to hydrochloric acid addition to the diet, resulted in more pronounced responses during the initial weeks postweaning than during the subsequent period. This suggests that hydrochloric acid secretion may be initially inadequate in weanling pigs. Thus, the addition of dietary hydrochloric acid would supply a needed source of chloride for pepsinogen activation, which could improve protein digestion. Until now, effect of inorganic acids in pig production has not yet been fully investigated, but combinations of organic acids with inorganic acids, mainly phosphoric acid, have received much attention (Table 13).

6. Existence/status/availability of branded products

The inclusion of acidifiers in diets has been found to be advantageous to the swine production industry. Earlier studies have shown improvements in pig performance as well as health status when acid is added to the diet and the current data also confirm this efficacy of acids. Apparently, acidifiers have emerged to be one of the promising available alternatives to substitute for antibiotics as growth promoters in pig diets. Therefore, there are presently a great number of acidifiers commercially available for the purpose of improving the pigs' performance and health.

Acidifiers are traded under a range of products with different active components and forms (Table 13). They are mostly available in a combination of acids (formed from multiple types of organic acids or both organic and inorganic acids), but individual acids are also seen in the market. Fumaric, lactic, citric, and phosphoric acids are often included in acid products. Additionally, acid products are manufactured in powder and liquid forms which are thought to be easy for feed handling as well as to be ideal for liquid feeding. Furthermore, pigs can be provided with acidifiers via diets or drinking water.

Lately, scientists have developed an innovative form of acidifiers called protected acids. This product is coated and protected by a matrix of fatty acids. It is rather stable and slow-released so that an acidic condition is expectedly maintained along the gastrointestinal tract. Particularly, protected acidifiers can reach the hind gut to produce an unfavorable medium for the growth of pathogenic bacteria (Mroz, 2003). According to Von Felde and Rudat (1998), the technology of microencapsulation and coating is also exploited to help avoid loss of feed palatability via masking acrid odor when diets are acidified. However, there is little published information about the efficacy of protected acidifiers in pigs. Thus, more studies are needed to assess the response of pigs to dietary protected acidifiers, but economical effectiveness should be taken into account when adding them to pig diets.

7. Existing patents

We currently have no information about existing patents of acid products.

8. Summary

From the present review it can be concluded that the inclusion of various organic acids or their salts to diet can positively improve the growth performance of pigs of different ages across a wide range of situations. The beneficial effects of organic acids on growth performance are most evident within the first few weeks of weaning, and the influence gradually decreases as the pig increases in age. Diet acidification significantly reduces the diet pH, but does not affect the gastrointestinal pH. The improvement in nutrient digestibility and the changes in microbial population are the important effects possibly caused by acidifiers.

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Table 1. Summary of Effect of Acids on Diet and Digesta pH Values

			Number of observations				
Description	**Control**	**Acid**	**Total**	**Positive**	**Negative**	**Equal**	**P [a]**
Diet	5.95	4.71	59	0 (0.0%)	58 (98.3%)	1 (1.7%)	0.0001
Stomach	3.73	3.66	22	9 (36.4%)	11 (54.6%)	2 (9.0%)	0.519
Small intestine	6.83	6.95	12	6 (50.0%)	6 (50.0%)	0 (0.0%)	0.155
Cecum	6.14	6.14	11	7 (63.6%)	4 (36.4%)	0 (0.0%)	0.862
Colon	6.60	6.60	11	3 (27.3%)	8 (72.7%)	0 (0.0%)	0.906

[a]Probability of no difference from zero

This summary obtained from the data in appendices 1, 2, 3, and 4

Table 2. Effect of Organic Acids and Their Salts on Microorganisms ($\log_{10}$ per gram or ml) in Pigs' Stomach

		Organic acid (%)			
	Control	**Formic**	**Formic + Fumaric**	**Formic + Lactic**	**Formic + Lactic**
	0.00	**0.96**	**1.06**	**1.38**	**1.24**
Lactobacilllus [1]	7.99	7.31	6.43	7.73	6.84
Coliforms [1]	3.05	3.67	4.77	3.32	3.88

		Organic acid (%)	
	Control	**Fumaric**	**Citric**
	0.00	**1.50**	**1.50**
Lactobacilllus [2]	7.50	7.70	8.00
E.coli [2]	5.40	6.00	6.00

		Organic salt (%)	
	Control	**Sodium fumarate**	**Sodium propionate**
	0.00	**0.30**	**0.30**
Lactobacillus [3]	6.74	6.77	7.13
E.coli [3]	5.62	5.73	5.91

(1) Franco *et al.*, 2005; (2) Risley *et al.*, 1992; (3) Sutton *et al.*, 1991

Table 3. Effect of Organic Acids and Their Salts on Microorganisms (log_{10} per gram or ml) in Pigs' Small Intestine

		Increasing levels of Formic Acid (%)				
		0.00	**0.60**	**1.20**	**1.80**	**2.40**
Duodenum [1]	*Lactobacillus/Bifidobacterium*	6.30	6.40	5.90	6.20	5.70
	E.coli	2.90 [a]	3.50 [ab]	3.20 [ab]	4.40 [b]	3.70 [ab]
Jejunum [1]	*Lactobacillus/Bifidobacterium*	7.70	7.20	6.40	6.90	6.70
	E.coli	4.80	4.30	5.00	6.00	5.30
Ileum [1]	*Lactobacillus/Bifidobacterium*	8.00	8.20	7.30	7.40	7.80
	E.coli	6.60	6.80	6.30	7.40	6.50

		Formic acid and its salt (%)		
		Control	**Formic**	**Calcium formate**
		0.00	**1.25**	**1.80**
Duodenum [2]	*Lactobacillus/Bifidobacterium*	6.40	5.50	6.10
	E.coli	5.50 [a]	3.30 [b]	3.70 [b]
Jejunum [2]	*Lactobacillus/Bifidobacterium*	6.70	5.80	6.20
	E.coli	6.80 [a]	5.30 [b]	5.10 [b]
Ileum [2]	*Lactobacillus/Bifidobacterium*	7.20	6.60	7.20
	E.coli	7.90	6.80	7.00

		Organic acid (%)				
		Control	**Formic**	**Formic + Fumaric**	**Formic + Lactic**	**Formic + Lactic**
		0.00	**0.96**	**1.06**	**1.38**	**1.24**
Small intestine [3]	*Lactobacilllus*	7.85	7.20	6.53	7.06	6.50
	Coliforms	6.42 [a]	5.92 [ab]	5.34 [abc]	4.33 [c]	4.44 [bc]

		Fumaric acid (%)	
		0.00	**1.00**
Ileum [4]	*Lactobacillus/Bifidobacterium*	6.37	5.20
	E.coli	7.91	8.31

		Organic acid (%)		
		Control	**Fumaric**	**Citric**
		0.00	**1.50**	**1.50**
Jejunum [5]	*Lactobacilllus*	7.40	7.60	7.90
	E.coli	6.00	6.40	5.70

		Organic salt (%)		
		Control	**Sodium fumarate**	**Sodium propionate**
		0.00	**0.30**	**0.30**
Duodenum [6]	*Lactobacillus*	7.14	6.48	6.98
	E.coli	5.93	6.29	5.77

(1) Gedek *et al.*, 1992; (2) Kirchgessner *et al.*, 1992; (3) Franco *et al.*, 2005; (4) Gabert *et al.*, 1995); (5) Risley *et al.*, 1992; (6) Sutton *et al.*, 1991

Table 4. Effect of Organic Acids and Their Salts on Microorganisms (log_{10} per gram or ml) in Pigs' Large Intestine

		Increasing levels of Formic Acid (%)				
		0.00	**0.60**	**1.20**	**1.80**	**2.40**
Cecum [1]	*Lactobacillus/Bifidobacterium*	8.50 [a]	7.90 [ab]	7.30 [b]	7.60 [b]	7.70 [b]
	E.coli	7.00 [a]	5.70 [b]	5.70 [b]	6.00 [b]	6.10 [b]
Colon [1]	*Lactobacillus/Bifidobacterium*	8.70 [a]	7.70 [b]	7.20 [b]	7.60 b	7.60 [b]
	E.coli	7.20 [a]	6.40 [b]	5.90 [b]	5.90 [b]	6.10 b

		Formic acid and its salt (%)		
		Control	**Formic**	**Calcium formate**
		0.00	**1.25**	**1.80**
Cecum [2]	*Lactobacillus/Bifidobacterium*	8.10	7.50	7.80
	E.coli	6.80	6.90	6.80
Colon [2]	*Lactobacillus/Bifidobacterium*	8.60	8.00	8.20
	E.coli	6.30	6.00	5.90

		Organic acid (%)		
		Control	**Fumaric**	**Citric**
		0.00	**1.50**	**1.50**
Cecum [3]	*Lactobacilllus*	8.90	9.00	9.20
	E.coli	7.40	7.60	7.90
Colon [3]	*Lactobacilllus*	6.00	6.40	5.70
	E.coli	7.30	7.40	7.20

		Organic salt (%)		
		Control	**Sodium fumarate**	**Sodium propionate**
		0.00	**0.30**	**0.30**
Cecum [4]	*Lactobacillus*	8.50	8.25	8.78
	E.coli	6.71	6.96	6.76
Colon [4]	*Lactobacillus*	8.88	8.67	9.10
	E.coli	7.22	7.29	6.98

(1) Gedek *et al.*, 1992; (2) Kirchgessner *et al.*, 1992; (3) Risley *et al.*, 1992; (4) Sutton *et al.*, 1991

Table 5. Summary of Effects of Acids on Dry Matter and Crude Protein Digestibilities

Description	Mean, % [a]	Number of observations				P [b]
		Total	Positive	Negative	Equal	
Dry matter digestibility	0.82	49	32	15	2	0.0007
Crude protein digestibility	1.33	47	38	9	0	0.0001

[a]Mean percent difference between average daily gain of pigs fed the diet containing acid versus those fed the control diet

[b]Probability of no difference from zero

This summary obtained from the data in appendices 5 and 6

Table 6. Summary of Effects of Diet, Acid Type, and Acid Level on Response of Dry Matter Digestibility to Acids

Description	Mean, % [a]	Number of observations				P [b]
		Total	Positive	Negative	Equal	
Diet						0.023
Animal & plant origin feed ingredients	1.14	30	22	7	1	
Plant origin feed ingredients	0.32	19	10	8	1	
Acid type						0.033
Formic	0.71	23	17	5	1	
Fumaric	0.28	15	8	6	1	
Acid level						0.007
≤ 1.5%	1.20	23	16	6	1	
> 1.5%	0.48	26	16	9	1	

[a]Mean percent difference between average daily gain of pigs fed the diet containing acid versus those fed the control diet

[b]Probability of no difference between categories

This summary obtained from the data in appendices 5 and 6

Table 7. Summary of Effects of Diet, Acid Type, and Acid Level on Response of Crude Protein Digestibility to Acids

Description	Mean, % [a]	Number of observations				P [b]
		Total	Positive	Negative	Equal	
Diet						0.169
Animal & plant origin feed ingredients	1.60	30	27	3	0	
Plant origin feed ingredients	0.86	17	11	6	0	
Acid type						0.033
Formic	1.64	23	20	3	0	
Fumaric	0.57	16	10	6	0	
Acid level						0.941
≤ 1.5%	1.33	23	19	4	0	
> 1.5%	1.33	24	19	5	0	

[a]Mean percent difference between average daily gain of pigs fed the diet containing acid versus those fed the control diet

[b]Probability of no difference between categories

This summary obtained from the data in appendices 5 and 6

Table 8. Summary of Acid Effects on Growth Rate in Weanling, Growing, and Finishing Pigs

Description	Mean, % [a]	Number of observations				P [b]
		Total	Positive	Negative	Equal	
Weanling pigs						
0 - 2 week post-weaning	12.25	50	36	12	2	0.0002
0 - 4 week post-weaning	6.03	78	59	17	2	0.0001
Growing pigs	3.52	30	19	11	0	0.0150
Finishing pigs	2.69	9	8	1	0	0.0220

[a]Mean percent difference between average daily gain of pigs fed the diet containing acid versus those fed the control diet

[b]Probability of no difference from zero

This summary obtained from the data in appendices 7, 8, 9, and 10

Table 9. Summary of Effect of Acids on Growth Rate in Pigs Challenged with Stress and Diseases

Description	Mean, % [a]	Number of observations				P [b]
		Total	Positive	Negative	Equal	
Challenges	9.35	11	10	1	0	0.006

[a]Difference between acid and control treatments, expressed as % of control value

[b]Probability of no difference from zero

This summary obtained from the data in appendix 11

Table 10. Summary of Effects of Diet, Acid Type, Acid Level, Weaning Age, and Performance Level on Response of Growth Performance of Weanling Pigs to Acids (0 – 2 week post-weaning period)

Description	Mean, % [a]	Number of observations				P [b]
		Total	Positive	Negative	Equal	
Diet						0.512
Animal & plant origin feed ingredients	13.33	15	9	5	1	
Plant origin feed ingredients	10.45	24	18	5	1	
Acid type						0.702
Citric	10.59	15	8	6	1	
Fumaric	15.56	17	14	2	1	
Acid level						0.197
≤ 1.5%	9.27	19	11	7	1	
> 1.5%	13.73	20	16	3	1	
Weaning age						0.472
≤ 28 days	9.13	18	13	4	1	
> 28 days	13.64	21	14	6	1	
Performance level						0.217
< 152 g/day	15.76	24	18	5	1	
> 152 g/day	4.83	15	9	5	1	

[a]Mean percent difference between average daily gain of pigs fed the diet containing acid versus those fed the control diet

[b]Probability of no difference between categories

This summary obtained from the data in appendix 7

Table 11. Summary of Effects of Diet, Acid Type, Acid Level, Weaning Age, and Performance Level on Response of Growth Performance of Weanling Pigs to Acids (0 – 4 week post-weaning period)

Description	Mean, % [a]	Number of observations				P [b]
		Total	Positive	Negative	Equal	
Diet						0.650
Animal & plant origin feed ingredients	6.72	37	31	5	1	
Plant origin feed ingredients	4.25	38	26	11	1	
Acid type						0.974
Citric	4.76	32	24	7	1	
Fumaric	4.68	28	21	6	1	
Acid level						0.616
≤ 1.5%	5.43	36	26	8	2	
> 1.5%	5.50	39	31	8	0	
Weaning age						0.949
≤ 28 days	5.59	47	38	8	1	
> 28 days	5.26	28	19	8	1	
Performance level						0.828
< 315 g/day	4.72	33	22	10	1	
> 315 g/day	6.06	42	35	6	1	

[a]Mean percent difference between average daily gain of pigs fed the diet containing acid versus those fed the control diet

[b]Probability of no difference from zero

This summary obtained from the data in appendix 8

Table 12. Summary of Effects of Diet, Acid Type, Acid Level, and Performance Level on Response of Growth Performance of Growing Pigs to Acids

Description	Mean, % [a]	Number of observations				P [b]
		Total	Positive	Negative	Equal	
Diet						0.370
Animal & plant origin feed ingredients	3.67	17	11	6	0	
Plant origin feed ingredients	3.32	13	8	5	0	
Acid type						0.824
Formic	3.17	11	6	5	0	
Formate	4.81	9	7	2	0	
Acid level						0.967
≤ 1.5%	5.35	14	11	3	0	
> 1.5%	1.91	16	8	8	0	
Performance level						0.214
< 665 g/day	2.25	12	6	6	0	
> 665 g/day	4.36	18	13	5	0	

[a]Mean percent difference between average daily gain of pigs fed the diet containing acid versus those fed the control diet

[b]Probability of no difference from zero

This summary obtained from the data in appendix 9

Table 13. Partial listing of manufacturers and acidifiers available to the pork production industry

Name of manufacturers	Products	Components	Forms
Agil Ltd.	BACT-A-START	Organic and inorganic acids	Liquid
Agil Ltd.	BUT-ACID	Salt of n-butyric acid	Liquid and powder
Biomin	Biotronic®	Organic acids and their salts	Powder
Canadian Bio-Systems Inc.	Acidifying agent OSP 82450	Organic and inorganic acids	Powder
Franklin Products Int. B.V.	FRA®ACID	Organic acids	Liquid and powder
Gateway Bio-Nutrients Inc.	Sal-B-Gon	Organic acids and their salts	Liquid and powder
Impextraco N.V.	ACIDAl® NC	Organic acids and their salts	Powder
Impextraco N.V.	ACIDAl® Cal	Salts of organic acids	Powder
Impextraco N.V.	ACIDAl® Lactic	Lactic acid	Powder
Impextraco N.V.	ACIDAl® ML	Organic acids	Powder
Industrial Tecnica Pecuaria S.A.	Digestocap	Organic and inorganic acids	Powder
Industrial Tecnica Pecuaria S.A.	Lacticap	Organic acids	Powder
[1]Jefo USA Inc.	Tetracid 500™	Organic acids and phosphoric acid	Powder, encapsulated
Kemin Agrifoods North America	Acid LAC®	Organic acids	Powder
Kemin Agrifoods North America	Kem-Gest™	Organic acids and phosphoric acid	Powder
Lucta USA Inc.	Luctacid HC®	Organic acids and phosphoric acid	Powder
Novus International Inc.	ACTIVATE WD Max	Organic acids	Liquid
Novus International Inc.	ACTIVATE Starter	Organic acids	Powder
Novus International Inc.	ACTIVATE Starter DA	Organic acids	Powder
Novus International Inc.	ACTIVATE Multimax	Organic acids	Powder
Novus International Inc.	ACTIVATE Grower	Organic acids	Powder
Profood International Inc.	Citric, Fumaric, Lactic, Malic	Organic acids	Powder
Selko B.V.	Selacid®	Organic acids	Powder
Selko B.V.	Selacid® -Green Growth	Organic acids	Powder
Selko B.V.	Selacid® - H+	Organic acids	Powder
Selko B.V.	Selacid® - PX	Organic acids	Powder
[2]Soda Feed Ingredients LLC	ACIPROL	Organic acids and orthophosphoric acid	Powder, encapsulated
[2]Soda Feed Ingredients LLC	AciXol	Organic acids and orthophosphoric acid	Powder, encapsulated

[1]Coated with hydrogenated vegetable oil
[2]Coated with RepaXol essential oil

Appendices

Appendix 1. Effect of Acids on Diet pH

Reference	Description	Acid type	Acid level, %	Control	Acid	Difference
Blank *et al.*, 1999	Experiment 1, low buffering capacity	Fumaric	1.00	5.20	4.70	-0.50
Blank *et al.*, 1999	Experiment 1, low buffering capacity	Fumaric	2.00	5.20	4.30	-0.90
Blank *et al.*, 1999	Experiment 1, low buffering capacity	Fumaric	3.00	5.20	4.00	-1.20
Blank *et al.*, 1999	Experiment 1, high buffering capacity	Fumaric	1.00	7.40	6.30	-1.10
Blank *et al.*, 1999	Experiment 1, high buffering capacity	Fumaric	2.00	7.40	5.30	-2.10
Blank *et al.*, 1999	Experiment 1, high buffering capacity	Fumaric	3.00	7.40	4.70	-2.70
Bolduan *et al.*, 1988	Experiment 1	Propionic	0.30	6.05	5.60	-0.45
Bolduan *et al.*, 1988	Experiment 1	Propionic	1.00	6.05	5.17	-0.88
Bolduan *et al.*, 1988	Experiment 1	Formic	0.35	6.05	5.41	-0.64
Bolduan *et al.*, 1988	Experiment 1	Formic	1.20	6.05	4.64	-1.41
Burnell *et al.*, 1988	Experiment 1	Citric & Sodium citrate	1.00	5.78	5.49	-0.29
Burnell *et al.*, 1988	Experiment 1	Citric & Sodium citrate	1.00	5.75	5.24	-0.51
Burnell *et al.*, 1988	Experiment 2	Citric & Sodium citrate	0.50	5.74	5.62	-0.12
Burnell *et al.*, 1988	Experiment 2	Citric & Sodium citrate	1.00	5.74	5.46	-0.28
Burnell *et al.*, 1988	Experiment 2	Citric & Sodium citrate	0.50	5.68	5.50	-0.18
Burnell *et al.*, 1988	Experiment 2	Citric & Sodium citrate	1.00	5.68	5.41	-0.27
Burnell *et al.*, 1988	Experiment 4	Citric & Sodium citrate	1.00	5.60	5.00	-0.60
Burnell *et al.*, 1988	Experiment 4	Citric & Sodium citrate	1.00	5.58	5.01	-0.57
Eckel *et al.*, 1992	Experiment 1, prestarter diet	Formic	0.60	6.03	5.21	-0.82
Eckel *et al.*, 1992	Experiment 1, prestarter diet	Formic	1.20	6.03	4.77	-1.26
Eckel *et al.*, 1992	Experiment 1, prestarter diet	Formic	1.80	6.03	4.21	-1.82
Eckel *et al.*, 1992	Experiment 1, prestarter diet	Formic	2.40	6.03	4.26	-1.77
Eckel *et al.*, 1992	Experiment 1, starter diet	Formic	0.60	5.77	4.99	-0.78
Eckel *et al.*, 1992	Experiment 1, starter diet	Formic	1.20	5.77	4.51	-1.26
Eckel *et al.*, 1992	Experiment 1, starter diet	Formic	1.80	5.77	4.21	-1.56
Eckel *et al.*, 1992	Experiment 1, starter diet	Formic	2.40	5.77	4.01	-1.76
Eidelsburger *et al.*, 1992a	Experiment 1, prestarter diet	HCL	1.40	6.15	4.70	-1.45
Eidelsburger *et al.*, 1992a	Experiment 1, prestarter diet	Formic	1.80	6.15	4.82	-1.33
Eidelsburger *et al.*, 1992a	Experiment 1, starter diet	HCL	1.40	6.03	4.61	-1.42
Eidelsburger *et al.*, 1992a	Experiment 1, starter diet	Formic	1.80	6.03	4.57	-1.46
Gabert and Sauer, 1995	Experiment 1	Fumaric	1.50	6.30	4.40	-1.90
Gabert and Sauer, 1995	Experiment 1	Fumaric	3.00	6.30	3.90	-2.40

Gabert and Sauer, 1995	Experiment 1	Sodium fumarate	1.50	6.30	6.30	0.00
Giesting and Easter, 1985	Experiment 1	Propionic	2.00	5.78	4.71	-1.07
Giesting and Easter, 1985	Experiment 1	Fumaric	2.00	5.78	4.18	-1.60
Giesting and Easter, 1985	Experiment 1	Citric	2.00	5.78	4.06	-1.72
Giesting and Easter, 1985	Experiment 2	Fumaric	1.00	5.96	4.77	-1.19
Giesting and Easter, 1985	Experiment 2	Fumaric	2.00	5.96	4.33	-1.63
Giesting and Easter, 1985	Experiment 2	Fumaric	3.00	5.96	3.98	-1.98
Giesting and Easter, 1985	Experiment 2	Fumaric	4.00	5.96	3.80	-2.16
Giesting and Easter, 1985	Experiment 3	Fumaric	1.50	5.94	4.32	-1.62
Giesting and Easter, 1985	Experiment 3	Fumaric	3.00	5.94	3.75	-2.19
Kirchgessner *et al.*, 1993	Experiment 1, prestarter diet	Malic	1.20	5.95	5.04	-0.91
Kirchgessner *et al.*, 1993	Experiment 1, prestarter diet	Malic	1.80	5.95	4.81	-1.14
Kirchgessner *et al.*, 1993	Experiment 1, prestarter diet	Malic	2.40	5.95	4.68	-1.27
Kirchgessner *et al.*, 1993	Experiment 1, starter diet	Malic	1.20	5.85	5.04	-0.81
Kirchgessner *et al.*, 1993	Experiment 1, starter diet	Malic	1.80	5.85	4.89	-0.96
Kirchgessner *et al.*, 1993	Experiment 1, starter diet	Malic	2.40	5.85	4.72	-1.13
Krause *et al.*, 1994	Experiment 1	Fumaric	2.50	5.73	3.65	-2.08
Krause *et al.*, 1994	Experiment 1	Malic	2.50	5.73	3.45	-2.28
Partanen *et al.*, 2001	Experiment 1, medium fiber diet	Formic	0.80	5.65	4.62	-1.03
Partanen *et al.*, 2001	Experiment 1, medium fiber diet	Sorbate	0.80	5.65	4.60	-1.05
Partanen *et al.*, 2001	Experiment 1, high fiber diet	Formic	0.80	5.41	4.50	-0.91
Partanen *et al.*, 2001	Experiment 1, high fiber diet	Sorbate	0.80	5.41	4.51	-0.90
Radcliffe *et al.*, 1998	Experiment 2	Citric	2.00	5.39	4.01	-1.38
Radcliffe *et al.*, 1998	Experiment 1	Citric	1.50	6.51	5.00	-1.51
Radcliffe *et al.*, 1998	Experiment 1	Citric	3.00	6.51	4.35	-2.16
Risley *et al.*, 1991	Experiment 1	Fumaric	1.50	6.42	4.70	-1.72
Risley *et al.*, 1991	Experiment 1	Citric	1.50	6.42	4.90	-1.52

Appendix 2. Effect of Acids on Stomach pH

Reference	Description	Acid	Rep.	Weaning age/ (day)	Age (day) at slaughter	Acid level, %	Control	Acid	Difference
Canibe *et al.*, 2001	Experiment 1	K-diformate	9	28	35	1.80	3.80	3.60	-0.20
Canibe *et al.*, 2005	Experiment 1	Formic	4	49 kg[2]	63 kg[2]	1.80	3.00	2.80	-0.20
Bolduan *et al.*, 1988	Experiment 1	Propionic	4	35	70	0.30	4.00	4.00	0.00
Bolduan *et al.*, 1988	Experiment 1	Propionic	4	35	70	1.00	4.00	3.90	-0.10
Bolduan *et al.*, 1988	Experiment 1	Formic	3	35	70	0.35	4.00	3.80	-0.20
Bolduan *et al.*, 1988	Experiment 1	Formic	3	35	70	1.20	4.00	3.70	-0.30
Burnell *et al.*, 1988	Experiment 1	Citric & sodium citrate	3	28	35	1.00	3.64	3.64	0.00
Eidelsburger *et al.*, 1992b	Experiment 1	Calcium formate	12	25	67	1.80	4.62	4.80	0.18
Eidelsburger *et al.*, 1992b	Experiment 1	Formic	12	25	67	1.25	4.62	3.95	-0.67
Franco *et al.*, 2005	Experiment 1	Formic	5	21	28	0.96	3.16	2.19	-0.97
Franco *et al.*, 2005	Experiment 1	Formic & Lactic	5	21	28	1.38	3.16	3.42	0.26
Franco *et al.*, 2005	Experiment 1	Formic & Lactic	5	21	28	1.24	3.16	3.30	0.14
Manzanilla *et al.*, 2004	Experiment 1	Formic	8	20	25	0.50	3.13	3.20	0.07
Radcliffe *et al.*, 1998	Experiment 2	Citric	8	27	62	2.00	3.60	3.33	-0.27
Risley *et al.*, 1991	Experiment 1	Fumaric	9	25	60	1.50	4.73	4.30	-0.43
Risley *et al.*, 1991	Experiment 1	Citric	9	25	60	1.50	4.73	4.83	0.10
Risley *et al.*, 1992	Experiment 1	Fumaric	6	21	< 42[1]	1.50	4.07	3.87	-0.20
Risley *et al.*, 1992	Experiment 1	Citric	6	21	< 42[1]	1.50	4.07	3.82	-0.25
Roth *et al.*, 1992	Experiment 1	Formic	9	28	69	0.60	3.16	3.54	0.38
Roth *et al.*, 1992	Experiment 1	Formic	9	28	69	1.20	3.16	3.69	0.53
Roth *et al.*, 1992	Experiment 1	Formic	9	28	69	1.80	3.16	3.68	0.52
Roth *et al.*, 1992	Experiment 1	Formic	9	28	69	2.40	3.16	3.21	0.05

[1]Mean pH value (pH measured at 2 d preweaning and 0, 3, 7, 14, and 21 d postweaning)

[2]Body weight

Appendix 3. Effect of Acids on Small Intestine pH

Reference	Description	Segments of intestine	Acid	Rep.	Weaning age (day)	Age (day) at slaughter	Acid level, %	Control	Acid	Difference
Canibe *et al.*, 2001	Experiment 1	Small intestine[1]	K-diformate	9	28	35	1.80	6.50	6.47	-0.03
Eidelsburger *et al.*, 1992b	Experiment 1	Duodenum	Calcium formate	12	25	67	1.80	6.75	6.82	0.07
Eidelsburger *et al.*, 1992b	Experiment 1	Duodenum	Formic	12	25	67	1.25	6.75	6.74	-0.01
Gabert *et al.*, 1995	Experiment 1	Ileum	Formic	3	21	32	1.00	7.66	7.82	0.16
Risley *et al.*, 1991	Experiment 1	Jejunum	Fumaric	9	25	60	1.50	7.06	7.01	-0.05
Risley *et al.*, 1991	Experiment 1	Jejunum	Citric	9	25	60	1.50	7.06	7.00	-0.06
Risley *et al.*, 1992	Experiment 1	Jejunum	Fumaric	6	21	< 42[2]	1.50	6.76	6.42	-0.34
Risley *et al.*, 1992	Experiment 1	Jejunum	Citric	6	21	< 42[2]	1.50	6.76	6.69	-0.07
Roth *et al.*, 1992	Experiment 1	Duodenum	Formic	9	28	69	0.60	6.66	7.08	0.42
Roth *et al.*, 1992	Experiment 1	Duodenum	Formic	9	28	69	1.20	6.66	6.93	0.27
Roth *et al.*, 1992	Experiment 1	Duodenum	Formic	9	28	69	1.80	6.66	7.17	0.51
Roth *et al.*, 1992	Experiment 1	Duodenum	Formic	9	28	69	2.40	6.66	7.26	0.60

[1]pH measured at three different sections of the small intestine (proximal, medial, and distal)

[2]Mean pH value (pH measured at 2 d preweaning and 0, 3, 7, 14, and 21 d postweaning)

Appendix 4. Effect of Acids on Large Intestine pH

Reference	Description	Segments of intestine	Acid	Rep.	Weaning age (day)	Age (day) at slaughter	Acid level, %	Control	Acid	Difference
Canibe *et al.*, 2001	Experiment 1	Cecum	K-diformate	9	28	35	1.80	6.40	6.00	-0.40
Eidelsburger *et al.*, 1992b	Experiment 1	Cecum	Calcium formate	12	25	67	1.80	6.54	6.64	0.10
Eidelsburger *et al.*, 1992b	Experiment 1	Cecum	Formic	12	25	67	1.25	6.54	6.43	-0.11
Risley *et al.*, 1991	Experiment 1	Cecum	Fumaric	9	25	60	1.50	5.96	6.04	0.08
Risley *et al.*, 1991	Experiment 1	Cecum	Citric	9	25	60	1.50	5.96	6.05	0.09
Risley *et al.*, 1992	Experiment 1	Cecum	Fumaric	6	21	< 42[1]	1.50	6.36	6.16	-0.20
Risley *et al.*, 1992	Experiment 1	Cecum	Citric	6	21	< 42[1]	1.50	6.36	6.19	-0.17
Roth *et al.*, 1992	Experiment 1	Cecum	Formic	9	28	69	0.60	5.85	5.90	0.05
Roth *et al.*, 1992	Experiment 1	Cecum	Formic	9	28	69	1.20	5.85	5.86	0.01
Roth *et al.*, 1992	Experiment 1	Cecum	Formic	9	28	69	1.80	5.85	6.25	0.40
Roth *et al.*, 1992	Experiment 1	Cecum	Formic	9	28	69	2.40	5.85	6.06	0.21
Canibe *et al.*, 2001	Experiment 1	Colon	K-diformate	9	28	35	1.80	6.60	6.57	-0.03
Eidelsburger *et al.*, 1992b	Experiment 1	Colon	Calcium formate	12	25	67	1.80	7.04	7.03	-0.01
Eidelsburger *et al.*, 1992b	Experiment 1	Colon	Formic	12	25	67	1.25	7.04	6.82	-0.22
Risley *et al.*, 1991	Experiment 1	Colon	Fumaric	9	25	60	1.50	6.51	6.53	0.02
Risley *et al.*, 1991	Experiment 1	Colon	Citric	9	25	60	1.50	6.51	6.47	-0.04
Risley *et al.*, 1992	Experiment 1	Colon	Fumaric	6	21	< 42[1]	1.50	7.06	6.89	-0.17
Risley *et al.*, 1992	Experiment 1	Colon	Citric	6	21	< 42[1]	1.50	7.06	6.93	-0.13
Roth *et al.*, 1992	Experiment 1	Colon	Formic	9	28	69	0.60	6.20	6.13	-0.07
Roth *et al.*, 1992	Experiment 1	Colon	Formic	9	28	69	1.20	6.20	6.12	-0.08
Roth *et al.*, 1992	Experiment 1	Colon	Formic	9	28	69	1.80	6.20	6.53	0.33
Roth *et al.*, 1992	Experiment 1	Colon	Formic	9	28	69	2.40	6.20	6.61	0.41

[1]Mean pH value (pH measured at 2 d preweaning and 0, 3, 7, 14, and 21 d postweaning)

Appendix 5. Effects of Acids on Dry Matter Digestibility

Reference	Description	Dietary animal protein source	Rep.	Pigs / pen	Diet [a]	Body weight (kg)	Acid type	Acid level, %	Digestibility, % Control	Acid	% Diff [b]	Weighting factor [c]
Blank *et al.*,1999	Experiment 1	No	3	1	Plant	4.7	Fumaric	1.00	86.1	86.4	0.3	0.704
Blank *et al.*,1999	Experiment 1	No	3	1	Plant	4.7	Fumaric	2.00	86.1	86.0	-0.1	0.704
Blank *et al.*,1999	Experiment 1	No	3	1	Plant	4.7	Fumaric	3.00	86.1	85.5	-0.7	0.704
Blank *et al.*,1999	Experiment 1, Na bicarbonate	No	3	1	Plant	5.6	Fumaric	1.00	85.1	86.1	1.2	0.781
Blank *et al.*,1999	Experiment 1, Na bicarbonate	No	3	1	Plant	5.6	Fumaric	2.00	85.1	85.4	0.8	0.781
Blank *et al.*,1999	Experiment 1, Na bicarbonate	No	3	1	Plant	5.6	Fumaric	3.00	85.1	85.1	0.0	0.781
Eckel *et al.*, 1992	Experiment 1, stage 1	Skim milk + Fish meal	5	9	Animal	6.1	Formic	0.60	88.4	89.2	0.9	0.490
Eckel *et al.*, 1992	Experiment 1, stage 1	Skim milk + Fish meal	5	9	Animal	6.1	Formic	1.20	88.4	89.6	1.4	0.490
Eckel *et al.*, 1992	Experiment 1, stage 1	Skim milk + Fish meal	5	9	Animal	6.0	Formic	1.80	88.4	89.7	1.5	0.490
Eckel *et al.*, 1992	Experiment 1, stage 1	Skim milk + Fish meal	5	9	Animal	6.1	Formic	2.40	88.4	89.7	1.5	0.490
Eckel *et al.*, 1992	Experiment 1, stage 2	Skim milk + Fish meal	5	9	Animal	14.7	Formic	0.60	89.3	89.8	0.6	0.455
Eckel *et al.*, 1992	Experiment 1, stage 2	Skim milk + Fish meal	5	9	Animal	15.3	Formic	1.20	89.3	89.3	0.0	0.455
Eckel *et al.*, 1992	Experiment 1, stage 2	Skim milk + Fish meal	5	9	Animal	15.1	Formic	1.80	89.3	89.2	-0.1	0.455
Eckel *et al.*, 1992	Experiment 1, stage 2	Skim milk + Fish meal	5	9	Animal	13.9	Formic	2.40	89.3	89.2	-0.1	0.455
Eidelsburger *et al.*, 1992c	Experiment 1, stage 1	Skim milk + Fish meal	6	12	Animal	6.4	Formate	1.80	89.1	89.8	0.8	0.833
Eidelsburger *et al.*, 1992c	Experiment 1, stage 1	Skim milk + Fish meal	6	12	Animal	6.4	Formic	1.25	89.1	89.3	0.2	0.833
Eidelsburger *et al.*, 1992c	Experiment 1, stage 1	Skim milk + Fish meal	6	12	Animal	6.4	Formate	1.80	88.9	89.6	0.8	0.833
Eidelsburger *et al.*, 1992c	Experiment 1, stage 1	Skim milk + Fish meal	6	12	Animal	6.4	Formic	1.25	88.9	89.1	0.2	0.833
Eidelsburger *et al.*, 1992c	Experiment 1, stage 2	Skim milk + Fish meal	6	12	Animal	13.7	Formate	1.80	87.7	88.7	1.1	0.385
Eidelsburger *et al.*, 1992c	Experiment 1, stage 2	Skim milk + Fish meal	6	12	Animal	14.3	Formic	1.25	87.7	88.2	0.6	0.385
Eidelsburger *et al.*, 1992c	Experiment 1, stage 2	Skim milk + Fish meal	6	12	Animal	13.6	Formate	1.80	88.4	88.2	-0.2	0.385
Eidelsburger *et al.*, 1992c	Experiment 1, stage 2	Skim milk + Fish meal	6	12	Animal	13.4	Formic	1.25	88.4	89.0	0.7	0.385
Eidelsburger *et al.*, 1992a	Experiment 1, stage 1	Skim milk + Fish meal	6	12	Animal	5.8	Fumaric	1.80	88.3	89.8	1.7	0.556
Eidelsburger *et al.*, 1992a	Experiment 1, stage 1	Skim milk + Fish meal	6	12	Animal	5.8	Formate	1.80	88.3	88.8	0.6	0.556
Eidelsburger *et al.*, 1992a	Experiment 1, stage 2	Skim milk + Fish meal	6	12	Animal	12.8	Fumaric	1.80	88.1	88.9	0.9	0.714
Eidelsburger *et al.*, 1992a	Experiment 1, stage 2	Skim milk + Fish meal	6	12	Animal	12.8	Formate	1.80	88.1	87.8	-0.3	0.714
Falkowski & Aherne, 1984	Experiment 1	Skim milk + Fish meal	11	2	Animal	8.7	Fumaric	1.00	80.8	80.6	-0.2	1.852
Falkowski & Aherne, 1984	Experiment 1	Skim milk + Fish meal	11	2	Animal	8.7	Fumaric	2.00	80.8	80.9	0.1	1.852
Falkowski & Aherne, 1984	Experiment 1	Skim milk + Fish meal	11	2	Animal	8.7	Citric	1.00	80.8	80.2	-0.7	1.852
Falkowski & Aherne, 1984	Experiment 1	Skim milk + Fish meal	11	2	Animal	8.7	Citric	2.00	80.8	80.9	0.1	1.852
Franco *et al.*, 2005	Experiment 1	Whey + Fish meal	3	2	Animal	5.4	Formic	0.96	77.4	80.4	3.9	2.500
Franco *et al.*, 2005	Experiment 1	Whey + Fish meal	3	2	Animal	5.4	Blend	1.06	77.4	81.8	5.7	2.500
Franco *et al.*, 2005	Experiment 1	Whey + Fish meal	3	2	Animal	5.4	Blend	1.38	77.4	81.7	5.6	2.500

Franco *et al.*, 2005	Experiment 1	Whey + Fish meal	3	2	Animal	5.4	Blend	1.24	77.4	82.1	6.1	2.500
Gabert & Sauer, 1995	Experiment 1	No	3	1	Plant	9.3	Fumaric	1.50	87.5	87.4	-0.1	0.926
Gabert & Sauer, 1995	Experiment 1	No	3	1	Plant	9.3	Fumaric	3.00	87.5	87.1	-0.5	0.926
Gabert & Sauer, 1995	Experiment 1	No	3	1	Plant	9.3	Fumarate	1.50	87.5	86.8	-0.8	0.926
Gabert *et al.*, 1995	Experiment 1	Fish meal	3	1	Animal	7.8	Formic	1.00	91.3	89.8	-1.6	0.877
Gabert *et al.*, 1995	Experiment 1, Ca carbonate	Fish meal	3	1	Animal	7.8	Formic	1.00	84.4	86.3	2.3	0.877
Mosenthin *et al.*, 1992	Experiment 1	No	16	1	Plant	50.0	Propionic	2.00	78.0	79.2	1.5	0.256
Mroz *et al.*, 2000	Experiment 1, Ca benzoate	No	5	1	Plant	30.0	Formic	1.38	81.7	82.0	0.4	1.220
Mroz *et al.*, 2000	Experiment 1, Ca benzoate	No	5	1	Plant	30.0	Fumaric	1.76	81.7	82.1	0.5	1.220
Mroz *et al.*, 2000	Experiment 1, Ca benzoate	No	5	1	Plant	30.0	Butyric	2.67	81.7	82.2	0.6	1.220
Mroz *et al.*, 2000	Experiment 1	No	5	1	Plant	30.0	Formic	1.38	80.6	81.5	1.1	1.220
Mroz *et al.*, 2000	Experiment 1	No	5	1	Plant	30.0	Fumaric	1.76	80.6	81.5	1.1	1.220
Mroz *et al.*, 2000	Experiment 1	No	5	1	Plant	30.0	Butyric	2.67	80.6	82.3	2.1	1.220
Radcliffe *et al.*, 1998	Experiment 1	No	4	2	Plant	7.4	Citric	1.50	81.3	81.1	-0.2	0.226
Radcliffe *et al.*, 1998	Experiment 1	No	4	2	Plant	7.4	Citric	3.00	81.3	81.0	-0.4	0.226
Radcliffe *et al.*, 1998	Experiment 1	No	8	2	Plant	9.6	Citric	2.00	79.5	78.8	-0.8	0.256

[a]Diet with animal and plant origin feed ingredients called "animal", diet with only plant origin feed ingredients called "plant"

[b]Difference between acid and control treatments, expressed as % of control value

[c]Weighting factor=1/(2*SEM)

Appendix 6. Effects of Acids on Crude Protein Digestibility

Reference	Description	Dietary animal protein source	Rep.	Pigs / pen	Diet [a]	Body weight (kg)	Acid type	Acid level, %	Digestibility, % Control	Digestibility, % Acid	Digestibility, % % Diff [b]	Weighting factor [c]
Blank *et al.*, 1999	Experiment 1	No	3	1	Plant	4.7	Fumaric	1.00	85.8	87.3	1.7	0.769
Blank *et al.*, 1999	Experiment 1	No	3	1	Plant	4.7	Fumaric	2.00	85.8	86.0	0.2	0.769
Blank *et al.*, 1999	Experiment 1	No	3	1	Plant	4.7	Fumaric	3.00	85.8	86.4	0.7	0.769
Blank *et al.*, 1999	Experiment 1, Na bicarbonate	No	3	1	Plant	5.6	Fumaric	1.00	85.5	87.0	1.8	0.735
Blank *et al.*, 1999	Experiment 1, Na bicarbonate	No	3	1	Plant	5.6	Fumaric	2.00	85.5	86.6	1.3	0.735
Blank *et al.*, 1999	Experiment 1, Na bicarbonate	No	3	1	Plant	5.6	Fumaric	3.00	85.5	84.9	-0.7	0.735
Eckel *et al.*, 1992	Experiment 1, stage 1	Skim milk + Fish meal	5	9	Animal	6.1	Formic	0.60	86.2	88.4	2.6	0.251
Eckel *et al.*, 1992	Experiment 1, stage 1	Skim milk + Fish meal	5	9	Animal	6.1	Formic	1.20	86.2	89.1	3.4	0.251
Eckel *et al.*, 1992	Experiment 1, stage 1	Skim milk + Fish meal	5	9	Animal	6.0	Formic	1.80	86.2	90.0	4.4	0.251
Eckel *et al.*, 1992	Experiment 1, stage 1	Skim milk + Fish meal	5	9	Animal	6.1	Formic	2.40	86.2	90.0	4.4	0.251
Eckel *et al.*, 1992	Experiment 1, stage 2	Skim milk + Fish meal	5	9	Animal	14.7	Formic	0.60	87.0	88.1	1.3	0.265
Eckel *et al.*, 1992	Experiment 1, stage 2	Skim milk + Fish meal	5	9	Animal	15.3	Formic	1.20	87.0	88.4	1.6	0.265
Eckel *et al.*, 1992	Experiment 1, stage 2	Skim milk + Fish meal	5	9	Animal	15.1	Formic	1.80	87.0	88.2	1.4	0.265
Eckel *et al.*, 1992	Experiment 1, stage 2	Skim milk + Fish meal	5	9	Animal	13.9	Formic	2.40	87.0	89.6	3.0	0.265
Eidelsburger *et al.*, 1992c	Experiment 1, stage 1	Skim milk + Fish meal	6	12	Animal	6.4	Formate	1.80	87.8	89.5	1.9	0.355
Eidelsburger *et al.*, 1992c	Experiment 1, stage 1	Skim milk + Fish meal	6	12	Animal	6.4	Formic	1.25	87.8	89.8	2.3	0.355
Eidelsburger *et al.*, 1992c	Experiment 1, stage 1	Skim milk + Fish meal	6	12	Animal	6.4	Formate	1.80	88.1	89.2	1.2	0.355
Eidelsburger *et al.*, 1992c	Experiment 1, stage 1	Skim milk + Fish meal	6	12	Animal	6.4	Formic	1.25	88.1	89.6	1.7	0.355
Eidelsburger *et al.*, 1992c	Experiment 1, stage 2	Skim milk + Fish meal	6	12	Animal	13.7	Formate	1.80	86.3	87.6	1.5	0.352
Eidelsburger *et al.*, 1992c	Experiment 1, stage 2	Skim milk + Fish meal	6	12	Animal	14.3	Formic	1.25	86.3	87.3	1.2	0.352
Eidelsburger *et al.*, 1992c	Experiment 1, stage 2	Skim milk + Fish meal	6	12	Animal	13.6	Formate	1.80	87.0	86.6	-0.5	0.352
Eidelsburger *et al.*, 1992c	Experiment 1, stage 2	Skim milk + Fish meal	6	12	Animal	13.4	Formic	1.25	87.0	88.3	1.5	0.352
Eidelsburger *et al.*, 1992a	Experiment 1, stage 1	Skim milk + Fish meal	6	12	Animal	5.8	Fumaric	1.80	87.1	89.3	2.5	0.244
Eidelsburger *et al.*, 1992a	Experiment 1, stage 1	Skim milk + Fish meal	6	12	Animal	5.8	Formate	1.80	87.1	87.5	0.5	0.244
Eidelsburger *et al.*, 1992a	Experiment 1, stage 2	Skim milk + Fish meal	6	12	Animal	12.8	Fumaric	1.80	86.4	87.1	0.8	0.239
Eidelsburger *et al.*, 1992a	Experiment 1, stage 2	Skim milk + Fish meal	6	12	Animal	12.8	Formate	1.80	86.4	85.4	-1.2	0.239
Falkowski & Aherne, 1984	Experiment 1	Skim milk + Fish meal	11	2	Animal	8.7	Fumaric	1.00	78.4	78.9	0.6	1.220
Falkowski & Aherne, 1984	Experiment 1	Skim milk + Fish meal	11	2	Animal	8.7	Fumaric	2.00	78.4	79.8	1.8	1.220
Falkowski & Aherne, 1984	Experiment 1	Skim milk + Fish meal	11	2	Animal	8.7	Citric	1.00	78.4	79.4	0.3	1.220
Falkowski & Aherne, 1984	Experiment 1	Skim milk + Fish meal	11	2	Animal	8.7	Citric	2.00	78.4	78.6	1.3	1.220
Franco *et al.*, 2005	Experiment 1	Whey + Fish meal	3	2	Animal	5.4	Formic	0.96	84.7	85.3	0.7	0.360
Franco *et al.*, 2005	Experiment 1	Whey + Fish meal	3	2	Animal	5.4	Blend	1.06	84.7	86.4	2.0	0.360

Franco *et al.*, 2005	Experiment 1	Whey + Fish meal	3	2	Animal	5.4	Blend	1.38	84.7	87.1	2.8	0.360
Franco *et al.*, 2005	Experiment 1	Whey + Fish meal	3	2	Animal	5.4	Blend	1.24	84.7	86.6	2.2	0.360
Gabert & Sauer, 1995	Experiment 1	No	3	1	Plant	9.3	Fumaric	1.50	89.2	89.0	-0.2	0.568
Gabert & Sauer, 1995	Experiment 1	No	3	1	Plant	9.3	Fumaric	3.00	89.2	88.4	-0.9	0.568
Gabert & Sauer, 1995	Experiment 1	No	3	1	Plant	9.3	Fumarate	1.50	89.2	87.8	-1.6	0.568
Gabert *et al.*., 1995	Experiment 1	Fish meal	3	1	Animal	7.8	Formic	1.00	88.5	86.9	-1.8	0.495
Gabert *et al.*., 1995	Experiment 1, Ca carbonate	Fish meal	3	1	Animal	7.8	Formic	1.00	84.6	86.8	2.6	0.495
Mosenthin *et al.*, 1992	Experiment 1	No	16	1	Plant	50.0	Propionic	2.00	80.2	82.5	2.9	0.213
Mroz *et al.*, 2000	Experiment 1, Ca benzoate	No	5	1	Plant	30.0	Formic	1.38	80.4	82.3	2.4	0.667
Mroz *et al.*, 2000	Experiment 1, Ca benzoate	No	5	1	Plant	30.0	Fumaric	1.76	80.4	82.4	2.5	0.667
Mroz *et al.*, 2000	Experiment 1, Ca benzoate	No	5	1	Plant	30.0	Butyric	2.67	80.4	82.4	2.5	0.667
Mroz *et al.*, 2000	Experiment 1	No	5	1	Plant	30.0	Formic	1.38	80.6	82.0	1.7	0.667
Mroz *et al.*, 2000	Experiment 1	No	5	1	Plant	30.0	Fumaric	1.76	80.6	79.6	-1.2	0.667
Mroz *et al.*, 2000	Experiment 1	No	5	1	Plant	30.0	Butyric	2.67	80.6	82.0	1.7	0.667
Radecki *et al.*, 1988	Experiment 1	No	4	1	Plant	8.2	Fumaric	1.50	84.5	84.3	-0.2	0.455

[a]Diet with animal and plant origin feed ingredients called "animal", diet with only plant origin feed ingredients called "plant"

[b]Difference between acid and control treatments, expressed as % of control value

[c]Weighting factor=1/(2*SEM)

Appendix 7. Effects of Acids on Growth Performance in Weanling pigs (0 - 2 week post-weaning period)

Reference	Description	Dietary animal protein source	Rep.	Pigs / pen	Diet [a]	Weaning age (day)	Acid type	Acid level, %	Average daily gain, g			Weighting factor [c]
									Control	Acid	% Diff [b]	
Edmonds *et al.*, 1985	Experiment 1	Whey + Fish meal	5	5	Animal	30	Citric	0.75	73	63	-13.6	0.025
Edmonds *et al.*, 1985	Experiment 2, antibiotic	Whey + Fish meal	5	5	Animal	30	Citric	0.75	91	60	-34.1	0.022
Edmonds *et al.*, 1985	Experiment 1, antibiotic	Whey + Fish meal	5	5	Animal	30	Citric	0.75	38	67	76.3	0.025
Edmonds *et al.*, 1985	Experiment 1	Whey + Fish meal	5	5	Animal	30	Citric	0.75	86	142	65.1	0.025
Edmonds *et al.*, 1985	Experiment 1	Whey + Fish meal	5	5	Animal	30	Citric	0.75	73	63	-37.4	0.025
Edmonds *et al.*, 1985	Experiment 2, antibiotic	Whey + Fish meal	5	5	Animal	30	Citric	1.50	91	141	54.9	0.022
Edmonds *et al.*, 1985	Experiment 5, antibiotic	Whey + Fish meal	5	4	Animal	30	Citric	1.50	168	165	-1.8	0.025
Edmonds *et al.*, 1985	Experiment 5, antibiotic	Whey + Fish meal	5	4	Animal	30	Fumaric	1.50	168	161	-4.2	0.025
Giesting *et al.*, 1991	Experiment 1	No	5	5	Plant	30	Fumaric	2.00	133	152	14.3	0.021
Giesting *et al.*, 1991	Experiment1	Skim milk	5	5	Animal	30	Fumaric	2.00	195	223	14.4	0.021
Giesting *et al.*, 1991	Experiment 3, NaHCO3	No	5	5	Plant	30	Fumaric	2.75	132	150	13.6	0.040
Giesting *et al.*, 1991	Experiment 3, NaHCO3	No	5	5	Plant	30	Fumaric	2.75	128	166	29.7	0.040
Giesting *et al.*, 1991	Experiment 3, NaHCO3	Casein	5	5	Animal	30	Fumaric	2.75	96	106	10.4	0.040
Giesting *et al.*, 1991	Experiment 3, NaHCO3	Casein	5	5	Animal	30	Fumaric	2.75	110	126	14.5	0.040
Giesting *et al.*, 1991	Experiment 1	No	5	5	Plant	30	Fumaric	3.00	133	171	28.6	0.021
Giesting *et al.*, 1991	Experiment 1	Skim milk	5	5	Animal	30	Fumaric	3.00	195	195	0.0	0.021
Giesting *et al.*, 1991	Experiment 2	No	8	5	Plant	30	Fumaric	3.00	123	174	41.5	0.038
Giesting *et al.*, 1991	Experiment 2	Casein	8	5	Animal	30	Fumaric	3.00	148	169	14.2	0.038
Krause *et al.*, 1994	Experiment 1	No	5	5	Plant	28	Citric	2.50	186	219	17.7	0.025
Krause *et al.*, 1994	Experiment, 1.4 % NaHCO3	No	5	5	Plant	28	Citric	2.50	186	174	-6.5	0.025
Krause *et al.*, 1994	Experiment 1	No	5	5	Plant	28	Fumaric	2.50	186	207	11.3	0.025
Krause *et al.*, 1994	Experiment 1, NaHCO3	No	5	5	Plant	28	Fumaric	2.50	186	247	32.8	0.025
Krause *et al.*, 1994	Experiment 1	No	5	5	Plant	28	Malic	2.50	186	200	7.5	0.025
Krause *et al.*, 1994	Experiment 1, NaHCO3	No	5	5	Plant	28	Malic	2.50	186	146	-21.5	0.025
Manzanilla *et al.*, 2004	Experiment 1	No	10	4	Plant	32	Formic	0.50	452	417	-7.7	0.044
Manzanilla *et al.*, 2004	Experiment 1	No	10	4	Plant	32	Formic	0.50	403	411	2.0	0.044
Manzanilla *et al..*, 2004	Experiment 1	No	10	4	Plant	32	Formic	0.50	423	447	5.7	0.044
Namkung et *al.*, 2004	Experiment 1	Whey + Fish meal	6	6	Animal	17	Blend	1.10	121	134	10.7	0.040
Namkung et *al.*, 2004	Experiment 1	Whey + Fish meal	6	6	Animal	17	Blend	2.10	121	158	30.6	0.040
Owusu-Asiedu *et al.*, 2003	Experiment1	Whey + Fish meal	5	3	Animal	10	Fumaric	2.00	156.6	155.4	-0.8	0.030
Owusu-Asiedu *et al.*, 2003	Experiment 1	Whey + Fish meal	5	3	Animal	10	Fumaric	2.00	100.9	155.4	54.0	0.030
Radcliffe *et al.*, 1998	Experiment 1	No	4	2	Plant	27	Citric	1.50	232	246	6.0	0.050
Radcliffe *et al.*, 1998	Experiment 1	No	4	2	Plant	27	Citric	3.00	232	271	16.8	0.059

Radecki *et al.*, 1988	Experiment 2	No	2	8	Plant	28	Citric	1.50	145	145	0.0	0.010
Radecki *et al.*, 1988	Experiment 1	No	2	8	Plant	28	Fumaric	1.50	112	143	27.7	0.021
Radecki *et al.*, 1988	Experiment 2	No	2	8	Plant	28	Citric	3.00	145	144	-0.7	0.010
Radecki *et al.*, 1988	Experiment 1	No	2	8	Plant	28	Fumaric	3.00	112	118	5.4	0.021
Risley *et al.*, 1993	Experiment 2, No *E.coli* challenge	No	4	2	Plant	21	Citric	1.50	49	56	14.3	0.125
Risley *et al.*, 1993	Experiment 2, *E.coli* challenge	No	4	2	Plant	21	Citric	1.50	55	56	1.8	0.125
Risley *et al.*, 1993	Experiment 2, No *E.coli* challenge	No	4	2	Plant	21	Fumaric	1.50	49	55	12.2	0.125
Risley *et al.*, 1993	Experiment 2, *E.coli* challenge	No	4	2	Plant	21	Fumaric	1.50	55	54	-1.8	0.125
Radcliffe *et al.*, 1998	Experiment 2	No	8	2	Plant	34	Citric	2.00	627	613	-2.2	0.021
Tsiloyiannis *et al.*, 2001a	Experiment 1, Diarrhoea outbreak	Fish meal	4	12	Animal	25	Propionic	1.00	150	165	10.0	NA
Tsiloyiannis *et al.*, 2001a	Experiment 1, Diarrhoea outbreak	Fish meal	4	12	Animal	25	Formic	1.20	150	175	16.7	NA
Tsiloyiannis *et al.*, 2001a	Experiment 1, Diarrhoea outbreak	Fish meal	4	12	Animal	25	Malic	1.20	150	168	12.0	NA
Tsiloyiannis *et al.*, 2001a	Experiment 1, Diarrhoea outbreak	Fish meal	4	12	Animal	25	Citric	1.50	150	167	11.3	NA
Tsiloyiannis *et al.*, 2001a	Experiment 1, Diarrhoea outbreak	Fish meal	4	12	Animal	25	Fumaric	1.50	150	172	14.7	NA
Tsiloyiannis *et al.*, 2001a	Experiment 1, Diarrhoea outbreak	Fish meal	4	12	Animal	25	Lactic	1.60	150	187	24.7	NA
Tsiloyiannis *et al.*, 2001b	Experiment 1, Oedema disease	No	4	12	Plant	28	Lactic	1.60	170	189	11.2	NA
Tsiloyiannis *et al.*, 2001b	Experiment 1, Oedema disease	No	4	12	Plant	28	Citric	1.50	170	187	10.0	NA

[a]Diet with animal and plant origin feed ingredients called "animal", diet with only plant origin feed ingredients called "plant"

[b]Difference between acid and control treatments, expressed as % of control value

[c]Weighting factor=1/(2*SEM)

NA = not available

Appendix 8. Effects of Acids on Growth Performance in Weanling pigs (0 – 4 week post-weaning period)

Reference	Description	Dietary animal protein source	Rep.	Pigs / pen	Diet [a]	Weaning age (day)	Acid type	Acid level, %	Average daily gain, g Control	Acid	% Diff [b]	Weighting factor [c]
Boling *et al.*, 2000	Experiment 5	No	3	3	Plant	34	Citric	1.00	344	371	7.80	0.031
Boling *et al.*, 2000	Experiment 5	No	3	3	Plant	34	Citric	2.00	344	398	15.70	0.031
Boling *et al.*, 2000	Experiment 5	No	3	3	Plant	34	Citric	3.00	344	379	10.20	0.031
Burnell *et al.*, 1988	Experiment 1	No	3	6	Plant	28	Citric+Citrate	1.00	299	332	11.00	0.038
Burnell *et al.*, 1988	Experiment 1	Whey	3	6	Animal	28	Citric+Citrate	1.00	323	328	1.50	0.038
Burnell *et al.*, 1988	Experiment 2	No	5	6	Plant	28	Citric+Citrate	0.50	288	318	10.40	0.038
Burnell *et al.*, 1988	Experiment 2	No	5	6	Plant	28	Citric+Citrate	1.00	288	311	8.00	0.038
Burnell *et al.*, 1988	Experiment 2	Whey	5	6	Animal	28	Citric+Citrate	0.50	327	336	2.80	0.038
Burnell *et al.*, 1988	Experiment 2	Whey	5	6	Animal	28	Citric+Citrate	1.00	327	348	6.40	0.038
Burnell *et al.*, 1988	Experiment 2	Whey	4	5	Animal	28	Citric+Citrate	1.00	356	359	0.80	0.066
Burnell *et al.*, 1988	Experiment 2	Whey	4	5	Animal	28	Citric+Citrate	1.00	398	419	5.30	0.066
Burnell *et al.*, 1988	Experiment 4, antibiotic	Whey	5	5	Animal	28	Citric+Citrate	1.00	361	361	0.00	0.029
Burnell *et al.*, 1988	Experiment 4, antibiotic, Cu	Whey	5	5	Animal	28	Citric+Citrate	1.00	388	418	7.70	0.025
Eckel *et al.*, 1992	Experiment 1	Skim meal + Fish meal	5	9	Animal	25	Formic	0.60	334	412	23.40	0.009
Eckel *et a..*, 1992	Experiment 1	Skim meal + Fish meal	5	9	Animal	25	Formic	1.20	334	439	31.40	0.009
Eckel *et al.*, 1992	Experiment 1	Skim meal + Fish meal	5	9	Animal	25	Formic	1.80	334	431	29.00	0.009
Eckel *et al.*, 1992	Experiment 1	Skim meal + Fish meal	5	9	Animal	25	Formic	2.40	334	372	11.40	0.009
Edmonds *et al.*, 1985	Experiment 1	Whey + Fish meal	5	5	Animal	30	Citric	0.75	257	241	-6.20	0.025
Edmonds *et al.*, 1985	Experiment 1, antibiotic	Whey + Fish meal	5	5	Animal	30	Citric	0.75	238	273	14.70	0.025
Edmonds *et al.*, 1985	Experiment 1, Cu	Whey + Fish meal	5	5	Animal	30	Citric	0.75	276	295	6.90	0.025
Edmonds *et al.*, 1985	Experiment 1, antibiotic, Cu	Whey + Fish meal	5	5	Animal	30	Citric	0.75	359	353	-1.70	0.025
Edmonds *et al.*, 1985	Experiment 2, antibiotic	Whey + Fish meal	5	5	Animal	30	Citric	0.75	246	224	-8.90	0.022
Edmonds *et al.*, 1985	Experiment 2, antibiotic	Whey + Fish meal	5	5	Animal	30	Citric	1.50	246	322	30.90	0.022
Edmonds *et al.*, 1985	Experiment 5, antibiotic, Cu	Whey + Fish meal	5	4	Animal	30	Citric	1.50	366	337	-7.90	0.028
Edmonds *et al.*, 1985	Experiment 5, antibiotic, Cu	Whey + Fish meal	5	4	Animal	30	Fumaric	1.50	366	389	6.30	0.028
Eidelsburger *et al.*, 1992c	Experiment 1, stage 1	Skim meal + Fish meal	6	12	Animal	25	Formate	1.80	337	346	2.70	0.006
Eidelsburger *et al.*, 1992c	Experiment 1, stage 1	Skim meal + Fish meal	6	12	Animal	25	Formic	1.25	337	375	11.30	0.006
Eidelsburger *et al.*, 1992c	Experiment 1, stage 1	Skim meal + Fish meal	6	12	Animal	25	Formate	1.80	325	344	5.80	0.006
Eidelsburger *et al.*, 1992c	Experiment 1, stage 1	Skim meal + Fish meal	6	12	Animal	25	Formic	1.25	325	333	2.50	0.006
Eidelsburger *et al.*, 1992a	Experiment 1, stage 1	Skim meal + Fish meal	6	12	Animal	24	Fumaric	1.80	336	323	-3.90	0.007
Eidelsburger *et al.*, 1992a	Experiment 1, stage 1	Skim meal + Fish meal	6	12	Animal	24	Formate	1.80	336	337	0.30	0.007
Falkowski & Aherne, 1984	Experiment 1	Skim milk + Fish meal	11	2	Animal	28	Fumaric	1.00	407	431	5.90	0.071

Falkowski & Aherne, 1984	Experiment 1	Skim milk + Fish meal	11	2	Animal	28	Fumaric	2.00	407	426	4.70	0.071
Falkowski & Aherne, 1984	Experiment 1	Skim milk + Fish meal	11	2	Animal	28	Citric	1.00	407	423	3.90	0.071
Falkowski & Aherne, 1984	Experiment 1	Skim milk + Fish meal	11	2	Animal	28	Citric	2.00	407	437	7.40	0.071
Giesting & Easter, 1985	Experiment 1	No	8	6	Plant	30	Propionic	2.00	252	241	-4.40	0.045
Giesting & Easter, 1985	Experiment 1	No	8	6	Plant	30	Fumaric	2.00	252	264	4.80	0.045
Giesting & Easter, 1985	Experiment 1	No	8	6	Plant	30	Citric	2.00	252	260	3.20	0.045
Giesting & Easter, 1985	Experiment 2	No	4	5	Plant	30	Fumaric	1.00	261	261	0.00	0.034
Giesting & Easter, 1985	Experiment 2	No	4	5	Plant	30	Fumaric	2.00	261	257	-1.50	0.034
Giesting & Easter, 1985	Experiment 2	No	4	5	Plant	30	Fumaric	3.00	261	296	13.40	0.034
Giesting & Easter, 1985	Experiment 2	No	4	5	Plant	30	Fumaric	4.00	261	297	13.80	0.034
Giesting & Easter, 1985	Experiment 3	No	5	5	Plant	30	Fumaric	2.00	337	329	-2.40	0.031
Giesting & Easter, 1985	Experiment 3	No	5	5	Plant	30	Fumaric	2.00	276	281	1.80	0.031
Giesting & Easter, 1991	Experiment 1	No	17	1	Plant	24	Fumaric	2.00	231	265	14.70	0.017
Giesting & Easter, 1991	Experiment 1	Skim meal	17	1	Animal	24	Fumaric	2.00	421	423	0.50	0.017
Giesting *et al.*, 1991	Experiment 1	No	5	5	Plant	30	Fumaric	2.00	289	320	10.70	0.022
Giesting *et al.*, 1991	Experiment 1	No	5	5	Plant	30	Fumaric	3.00	289	311	7.60	0.022
Giesting *et al.*, 1991	Experiment 1	Skim milk	5	5	Animal	30	Fumaric	2.00	327	359	9.80	0.022
Giesting *et al.*, 1991	Experiment 1	Skim milk	5	5	Animal	30	Fumaric	3.00	327	350	7.00	0.022
Giesting *et al.*, 1991	Experiment 2	No	8	5	Plant	30	Fumaric	3.00	298	311	4.40	0.043
Giesting *et al.*, 1991	Experiment 2	Casein	8	5	Animal	30	Fumaric	3.00	292	330	13.00	0.043
Giesting *et al.*, 1991	Experiment 3	No	5	5	Plant	30	Fumaric	2.75	260	248	-4.60	0.037
Giesting *et al.*, 1991	Experiment 3	Casein	5	5	Animal	30	Fumaric	2.75	198	204	3.00	0.037
Henry *et al.*, 1985	Experiment 1	Skim meal + Fish meal	7	8	Animal	10	Citric	3.00	189	216	14.30	0.037
Henry *et al.*, 1985	Experiment 1	Skim meal + Fish meal	7	8	Animal	10	Fumaric	1.50	189	170	-10.10	0.037
Kirchgessner *et al.*, 1993	Experiment 1	Skim meal + Fish meal	4	12	Animal	25	Malic	1.20	334	352	5.40	0.006
Kirchgessner *et al.*, 1993	Experiment 1	Skim meal + Fish meal	4	12	Animal	25	Malic	1.80	334	355	6.30	0.006
Kirchgessner *et al.*, 1993	Experiment 1	Skim meal + Fish meal	4	12	Animal	25	Malic	2.40	334	365	9.30	0.006
Krause *et al.*, 1994	Experiment 1	No	5	5	Plant	28	Fumaric	2.50	330	364	10.30	0.025
Krause *et al.*, 1994	Experiment 1	No	5	5	Plant	28	Malic	2.50	330	340	3.00	0.025
Krause *et al.*, 1994	Experiment 1	No	5	5	Plant	28	Citric	2.50	330	348	5.50	0.025
Krause *et al.*, 1994	Experiment 1, 2.3 % NaHCO3	No	5	5	Plant	28	Fumaric	2.50	330	374	13.30	0.025
Krause *et al.*, 1994	Experiment 1, 1.9 % NaHCO3	No	5	5	Plant	28	Malic	2.50	330	296	-10.30	0.025
Krause *et al.*, 1994	Experiment1, 1.4 % NaHCO3	No	5	5	Plant	28	Citric	2.50	330	341	3.30	0.025
Radcliffe *et al.*, 1998	Experiment 1	No	4	2	Plant	27	Citric	1.50	313	336	7.30	0.050
Radcliffe *et al.*, 1998	Experiment 1	No	4	2	Plant	27	Citric	3.00	313	340	8.60	0.059
Radcliffe *et al.*, 1998	Experiment 2	No	8	2	Plant	34	Citric	2.00	797	786	-1.40	0.027
Radecki *et al.*, 1988	Experiment 1	No	2	8	Plant	28	Fumaric	1.50	245	244	-0.40	0.015

Radecki *et al.*, 1988	Experiment 1	No	2	8	Plant	28	Fumaric	3.00	245	216	-11.80	0.015
Radecki *et al.*, 1988	Experiment 2	No	2	8	Plant	28	Citric	1.50	307	282	-8.10	0.013
Radecki *et al.*, 1988	Experiment 2	No	2	8	Plant	28	Citric	3.00	307	304	-1.00	0.013
Risley *et al.*, 1991	Experiment 1	No	16	3	Plant	25	Fumaric	1.50	297	308	3.70	0.054
Risley *et al.*, 1991	Experiment 1	No	16	3	Plant	25	Citric	1.50	297	321	8.10	0.054
Risley *et al.*, 1991	Experiment 2, No micro.culture	No	8	4	Plant	25	Fumaric	1.50	313	330	5.40	0.040
Risley *et al.*, 1991	Experiment 2, No micro.culture	No	8	4	Plant	25	Citric	1.50	313	304	-2.90	0.040
Risley *et al.*, 1991	Experiment 2, Micro.culture	No	8	4	Plant	25	Fumaric	1.50	318	330	3.80	0.040
Risley *et al.*, 1991	Experiment 2, Micro.culture	No	8	4	Plant	25	Citric	1.50	318	315	-0.90	0.040
Tsiloyiannis *et al.*, 2001a	Experiment 1, Diarrhoea outbreak	Fish meal	4	12	Animal	25	Propionic	1.00	213	231	8.50	NA
Tsiloyiannis *et al.*, 2001a	Experiment 1, Diarrhoea outbreak	Fish meal	4	12	Animal	25	Lactic	1.60	213	259	21.60	NA
Tsiloyiannis *et al.*, 2001a	Experiment 1, Diarrhoea outbreak	Fish meal	4	12	Animal	25	Formic	1.20	213	244	14.60	NA
Tsiloyiannis *et al.*, 2001a	Experiment 1, Diarrhoea outbreak	Fish meal	4	12	Animal	25	Malic	1.20	213	235	10.30	NA
Tsiloyiannis *et al.*, 2001a	Experiment 1, Diarrhoea outbreak	Fish meal	4	12	Animal	25	Citric	1.50	213	236	10.80	NA
Tsiloyiannis *et al.*, 2001a	Experiment 1, Diarrhoea outbreak	Fish meal	4	12	Animal	25	Fumaric	1.50	213	241	13.10	NA
Tsiloyiannis *et al.*, 2001b	Experiment 1, Oedema disease	No	4	12	Plant	25	Lactic	1.60	228	260	14.00	NA
Tsiloyiannis *et al.*, 2001b	Experiment 1, Oedema disease	No	4	12	Plant	25	Citric	1.50	228	257	12.70	NA

[a]Diet with animal and plant origin feed ingredients called "animal", diet with only plant origin feed ingredients called "plant"

[b]Difference between acid and control treatments, expressed as % of control value

[c]Weighting factor=1/(2*SEM)

NA = not available

Appendix 9. Effects of Acids on Growth Performance in Growing Pigs

Reference	Description	Dietary animal protein source	Rep.	Pigs / pen	Diet [a]	Initial weight (kg)	Acid type	Acid level, %	Average daily gain, g			Weighting factor [c]
									Control	Acid	% Diff[b]	
Canibe *et al.*, 2005	Experiment 1	No	7	5	Plant	27.0	Formic	1.80	728	714	-1.9	0.021
Eckel *et al.*, 1992	Experiment 1	Fish meal + Skim milk	5	9	Animal	14.7	Formic	0.60	434	516	18.9	0.008
Eckel *et al.*, 1992	Experiment 1	Fish meal + Skim milk	5	9	Animal	15.3	Formic	1.20	434	498	14.7	0.008
Eckel *et al.*, 1992	Experiment 1	Fish meal + Skim milk	5	9	Animal	15.1	Formic	1.80	434	369	-15.0	0.008
Eidelsburger *et al.*, 1992c	Experiment 1, stage 2	Fish meal + Skim milk	6	12	Animal	13.7	Formate	1.80	501	483	-3.6	0.006
Eidelsburger *et al.*, 1992c	Experiment 1, stage 2	Fish meal + Skim milk	6	12	Animal	14.3	Formic	1.25	501	525	4.8	0.006
Eidelsburger *et al.*, 1992c	Experiment 1, stage 2	Fish meal + Skim milk	6	12	Animal	13.6	Formate	1.80	495	492	-0.6	0.006
Eidelsburger *et al.*, 1992c	Experiment 1, stage 2	Fish meal + Skim milk	6	12	Animal	13.4	Formic	1.25	495	494	-0.2	0.006
Eidelsburger *et al.*, 1992a	Experiment 1, stage 2	Fish meal + Skim milk	6	12	Animal	12.5	Fumaric	1.80	452	469	3.8	0.006
Eidelsburger *et al.*, 1992a	Experiment 1, stage 2	Fish meal + Skim milk	6	12	Animal	12.9	Formate	1.80	452	474	4.9	0.006
Jongbloed *et al.*, 2000	Experiment 1	No	3	6	Plant	22.0	Lactic	3.20	691	758	9.7	0.037
Jongbloed *et al.*, 2000	Experiment 1	No	3	6	Plant	22.0	Formic	1.60	691	758	9.7	0.037
Jongbloed *et al.*, 2000	Experiment 1	No	3	6	Plant	22.0	Lactic	3.20	772	836	8.3	0.037
Jongbloed *et al.*, 2000	Experiment 1	No	3	6	Plant	22.0	Formic	1.60	772	874	13.2	0.037
Kirchgessner *et al.*, 1993	Experiment 1	Fish meal + Skim milk	4	12	Animal	13.9	Malic	1.20	560	579	3.4	0.006
Kirchgessner *et al.*, 1993	Experiment 1	Fish meal + Skim milk	4	12	Animal	14.0	Malic	1.80	560	549	-2.0	0.006
Kirchgessner *et al.*, 1993	Experiment 1	Fish meal + Skim milk	4	12	Animal	14.2	Malic	2.40	560	548	-2.1	0.006
Mroz *et al.*, 2000	Experiment 1, No Ca benzoate	No	5	1	Plant	30.0	Formic	1.38	849	803	-5.4	0.006
Mroz *et al.*, 2000	Experiment 1, No Ca benzoate	No	5	1	Plant	30.0	Fumaric	1.76	849	843	-0.7	0.006
Mroz *et al.*, 2000	Experiment 1, No Ca benzoate	No	5	1	Plant	30.0	Butyric	2.67	849	909	7.1	0.006
Mroz *et al.*, 2000	Experiment 1, Ca benzoate	No	5	1	Plant	30.0	Formic	1.38	824	743	-9.8	0.006
Mroz *et al.*, 2000	Experiment 1, Ca benzoate	No	5	1	Plant	30.0	Fumaric	1.76	824	784	-4.9	0.006
Mroz *et al.*, 2000	Experiment 1, Ca benzoate	No	5	1	Plant	30.0	Butyric	2.67	824	863	4.7	0.006
Overland *et al.*, 2000	Experiment 1	Fish meal + Meat bone meal	12	6	Animal	23.0	Formate	0.85	752	758	0.8	0.056
Overland *et al.*, 2000	Experiment 1	Fish meal + Meat bone meal	12	6	Animal	23.0	Formate	0.80	752	797	6.0	0.056
Overland *et al.*, 2000	Experiment 2	Fish meal + Meat bone meal	5	1	Animal	24.3	Formate	0.80	855	957	11.9	0.012
Overland *et al.*, 2000	Experiment 3	Fish meal + Meat bone meal	32	1	Animal	27.0	Formate	0.60	748	793	6.0	0.038
Overland *et al.*, 2000	Experiment 3	Fish meal + Meat bone meal	32	1	Animal	27.0	Formate	1.20	748	828	10.7	0.038
Partanen *et al.*, 2001	Experiment 1	No	5	4	Plant	27.4	Formic	0.80	765	810	5.9	0.026
Partanen *et al.*, 2001	Experiment 1	No	5	4	Plant	27.4	Formate	0.80	765	820	7.2	0.026

[a]Diet with animal and plant origin feed ingredients called "animal", diet with only plant origin feed ingredients called "plant"

[b]Difference between acid and control treatments, expressed as % of control value

[c]Weighting factor=1/(2*SEM)

Appendix 10. Effects of Acids on Growth Performance in Finishing Pigs

Reference	Description	Dietary animal protein source	Rep.	Pigs / pen	Diet [a]	Initial weight (kg)	Acid	Acid level, %	Average daily gain, g			Weighting factor [c]
									Control	Acid	% Diff [b]	
Giesting & Easter, 1985	Experiment 4	No	9	5	Plant	47.5	Fumaric	1.50	790	810	2.5	0.031
Giesting & Easter, 1985	Experiment 4	No	9	5	Plant	47.5	Fumaric	3.00	790	820	3.8	0.031
Krause *et al.*, 1994	Experiment 3	No	5	5	Plant	65.0	Fumaric	2.50	860	880	2.3	0.050
Overland *et al.*, 2000	Experiment1	Fish meal + Meat bone meal	12	6	Animal	60.3	Formate	0.85	1118	1099	-1.7	0.026
Overland *et al.*, 2000	Experiment 1	Fish meal + Meat bone meal	12	6	Animal	62.0	Formate	0.80	1118	1130	1.1	0.026
Overland *et al.*, 2000	Experiment 3	Fish meal + Meat bone meal	32	1	Animal	62.8	Formate	0.60	980	986	0.6	0.036
Overland *et al.*, 2000	Experiment 3	Fish meal + Meat bone meal	32	1	Animal	64.3	Formate	1.20	980	1014	3.5	0.036
Partanen *et al.*, 2001	Experiment 1	No	5	4	Plant	56.0	Fumaric	0.80	917	948	3.4	0.031
Partanen *et al.*, 2001	Experiment 1	No	5	4	Plant	56.0	Formate	0.80	917	997	8.7	0.031

[a]Diet with animal and plant origin feed ingredients called "animal", diet with only plant origin feed ingredients called "plant"

[b]Difference between acid and control treatments, expressed as % of control value

[c]Weighting factor=1/(2*SEM)

Appendix 11. Effects of Acids on Growth Performance in Pigs Challenged with Stress and Diseases

Reference	Description	Dietary animal protein source	Rep.	Pigs / pen	Diet [a]	Weaning age (day)	Acid type	Acid level, %	Average daily gain, g		
									Control	**Acid**	**% Diff [b]**
Manzanilla *et al.*, 2004	Experiment 1, Stress challenge	No	10	4	Plant	20	Formic	0.5	452	417	-7.70
Risley *et al.*, 1993	Experiment 2, *E.coli* challenge	No	4	2	Plant	21	Fumaric	1.5	55	54	-1.80
Risley *et al.*, 1993	Experiment 2, *E.coli* challenge	No	4	2	Plant	21	Citric	1.5	55	56	1.80
Tsiloyiannis *et al.*, 2001a	Experiment 1, Diarrhoea outbreak	Fish meal	4	12	Animal	25	Propionic	1.0	213	231	10.00
Tsiloyiannis *et al.*, 2001a	Experiment 1, Diarrhoea outbreak	Fish meal	4	12	Animal	25	Lactic	1.6	213	259	24.70
Tsiloyiannis *et al.*, 2001a	Experiment 1, Diarrhoea outbreak	Fish meal	4	12	Animal	25	Formic	1.2	213	244	16.70
Tsiloyiannis *et al.*, 2001a	Experiment 1, Diarrhoea outbreak	Fish meal	4	12	Animal	25	Malic	1.2	213	235	12.00
Tsiloyiannis *et al.*, 2001a	Experiment 1, Diarrhoea outbreak	Fish meal	4	12	Animal	25	Citric	1.5	213	236	11.30
Tsiloyiannis *et al.*, 2001a	Experiment 1, Diarrhoea outbreak	Fish meal	4	12	Animal	25	Fumaric	1.5	213	241	14.70
Tsiloyiannis *et al.*, 2001b	Experiment 1, Oedema disease	No	4	12	Plant	25	Lactic	1.6	228	260	11.20
Tsiloyiannis *et al.*, 2001b	Experiment 1, Oedema disease	No	4	12	Plant	25	Citric	1.5	228	257	10.00

[a]Diet with animal and plant origin feed ingredients called "animal", diet with only plant origin feed ingredients called "plant"

[b]Difference between acid and control treatments, expressed as % of control value

Appendix 12. Effects of Acids on Diarrhea and Mortality of Pigs Non-challenged or Challenged with Stress and Diseases

Reference	Description	Dietary animal protein source	Rep.	Pigs / pen	Diet [a]	Weaning age (day)	Acid type	Acid level, %	Diarrhea		Mortality, %	
									Control	Acid	Control	Acid
Manzanilla *et al.*, 2004	Experiment 1, Stress challenge	No	10	4	Plant	20	Formic	0.5	2 [c]	2 [c]	5.00	5.00
Owusu-Asiedu *et al.*, 2003	Experiment 1	Whey + Fish meal	5	3	Animal	10	Fumaric	2.00	4 [d]	5 [d]	6.6	6.6
Owusu-Asiedu *et al.*, 2003	Experiment 1	Whey + Fish meal	5	3	Animal	10	Fumaric	2.00	7 [d]	5 [d]	40.0	6.6
Paulicks *et al.*, 2000	Experiment 1, low energy	Fish meal	12	1	Animal	28	Formate	1.8	20 [d]	3 [d]	NA	NA
Paulicks *et al.*, 2000	Experiment 1, high energy	Fish meal	12	1	Animal	28	Formate	1.8	28 [d]	10 [d]	NA	NA
Risley *et al.*, 1993	Experiment 2, *E.coli* challenge	No	4	2	Plant	21	Fumaric	1.5	NA	NA	NA	NA
Risley *et al.*, 1993	Experiment 2, *E.coli* challenge	No	4	2	Plant	21	Citric	1.5	NA	NA	NA	NA
Tsiloyiannis *et al.*, 2001a	Experiment 1, Diarrhoea outbreak	Fish meal	4	12	Animal	25	Propionic	1.0	5.63 [e]	4.41 [e]	12.50	6.25
Tsiloyiannis *et al.*, 2001a	Experiment 1, Diarrhoea outbreak	Fish meal	4	12	Animal	25	Lactic	1.6	5.63 [e]	1.94 [e]	12.50	4.17
Tsiloyiannis *et al.*, 2001a	Experiment 1, Diarrhoea outbreak	Fish meal	4	12	Animal	25	Formic	1.2	5.63 [e]	2.50 [e]	12.50	6.25
Tsiloyiannis *et al.*, 2001a	Experiment 1, Diarrhoea outbreak	Fish meal	4	12	Animal	25	Malic	1.2	5.63 [e]	3.49 [e]	12.50	6.25
Tsiloyiannis *et al.*, 2001a	Experiment 1, Diarrhoea outbreak	Fish meal	4	12	Animal	25	Citric	1.5	5.63 [e]	3.21 [e]	12.50	6.25
Tsiloyiannis *et al.*, 2001a	Experiment 1, Diarrhoea outbreak	Fish meal	4	12	Animal	25	Fumaric	1.5	5.63 [e]	3.00 [e]	12.50	4.16
Tsiloyiannis *et al.*, 2001b	Experiment 1, Oedema disease	No	4	12	Plant	25	Lactic	1.6	NA	NA	31.25	12.50
Tsiloyiannis *et al.*, 2001b	Experiment 1, Oedema disease	No	4	12	Plant	25	Citric	1.5	NA	NA	31.25	10.42

[a]Diet with animal and plant origin feed ingredients called "animal", diet with only plant origin feed ingredients called "plant"

[b]Difference between acid and control treatments, expressed as % of control value

[c]Number of pens presenting liquid feces 2 days after the beginning of the diarrhea episode (2 days after diet change). No liquid feces was detected the following days of experiment

[d]Diarrhea days

[e]Diarrhea score, 0 = no diarrhea, 1 = soft feces, 2 = fluid feces, 3 = projectile diarrhea

NA = not available