NUTRITIVE AND ANTIMICROBIAL EFFECTS OF ORGANIC ACIDS IN PIGS

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SUMMARY

In this review the effect of a dietary inclusion of organic acids on health and performance of pigs are discussed. Aspects considered are organic acid characteristics, and the effects of organic acid utilization on gastric pH and animal performance, as well as anti-microbial and other influences.

The mode of action of organic acids is two fold referring to the fact that they consist of a proton and anion. The proton effect of an organic acid is based on the acidification of feed and digesta and the anion effect on its ability to inhibit growth of microbes. The extent of the anti-microbial properties of organic acids depends on their ability to change from the undissociated to the dissociated form. The latter is mainly influenced by the environmental pH relative to their pKa value. The pKa value indicates at which pH 50% of the acid is dissociated. In their undissociated form organic acids passively diffuse through the bacterial wall and interfere with the fine-tuned pH balance in the cytoplasm, which upsets the energy balance and disrupts biochemical processes. Suppression of cellular enzymes transport systems is also reported, which prevents bacteria from multiplying.

It is considered that organic acids are used for many applications in human and animal nutrition. The use for the preservation of foodstuffs or single components is accepted all over the world as a very effective method to control growth of bacteria (Escherichia coli, Salmonellae), mold and yeast. There is ample evidence that organic acids can improve performance of piglets and to a lower extent also those of growing pigs.

Key words: pigs, organic acids, nutrition, health

Short title: Organic acids for pigs

EFECTOS NUTRICIONALES Y ANTIMICROBIANOS DE LOS ACIDOS ORGANICOS EN CERDOS

RESUMEN

En esta reseña se discute el efecto en la salud y comportamiento de los cerdos por la inclusión en la dieta de los ácidos orgánicos. Los aspectos considerados son las características de los ácidos orgánicos, y los efectos de la utilización de ácidos orgánicos en el pH gástrico y en el comportamiento animal, así como la influencia antimicrobiana y otras.

El modo de acción de los ácidos orgánicos es doble, en referencia al hecho de que ellos consisten en un protón y un anión. El efecto del protón de un ácido orgánico se basa en la acidificación del alimento y de la digesta, mientras que el efecto del anión radica en su habilidad para inhibir el crecimiento de los microbios. La extensión de las propiedades antimicrobianas de los ácidos orgánicos dependen de la habilidad para cambiar de la forma no disociada a la otra disociada. Esta última es influída principalmente por el pH del medio en relación con su valor de pKa. El valor del pKa indica a cuál pH un 50% del ácido está disociado. En su forma no disociada, los ácidos orgánicos se difunden pasivamente a través de la pared bacteriana e interfieren con el fino balance del citoplasma, y así alteran el balance energético e interrumpen los procesos bioquímicos. La supresión de los sistemas de transporte celular también ha sido informada, lo que previene la multiplicación bacteriana.

Se considera que los ácidos orgánicos son usados para muchas aplicaciones en la nutrición humana y animal. En todo el mundo se acepta su uso para la preservación de comidas o de componentes individuales, como un método muy efectivo para controlar el crecimiento bacteriano (Escherichia coli, Salmonellae), hongos y levaduras. Hay una evidencia amplia de que los ácidos orgánicos pueden mejorar el comportamiento de los cerditos y en menor extensión, el de los cerdos en crecimiento.

Palabras claves: cerdos, ácidos orgánicos, salud, nutrición

Título corto: Ácidos orgánicos para cerdos
Organic acids are used for many applications in human and animal nutrition. The use for the preservation of foodstuffs or single components is accepted all over the world as a very effective method to control growth of bacteria (Escherichia coli, Salmonellae), mold and yeast. There is ample evidence that organic acids can improve performance of piglets and to a lower extent also those of growing pigs. The mode of action of organic acids is two fold referring to the fact that they consist of a proton and anion. The proton effect of an organic acid is based on the acidification of feed and digesta and the anion effect on its ability to inhibit growth of microbes.

Looking at it simplistically from a pH point of view only, it is possible to inhibit growth of different bacteria by creating an undesirable pH due to pH sensitivity of bacteria. This pH sensitivity of such microorganism is reviewed in table 2.

In principle many organic acids are available for application in pig nutrition. The product chosen depends on several factors such as efficacy, costs, handling conditions, et cetera. Short chain organic acids are the most common organic acids used in pig nutrition. Most of the organic acids are liquid, but some are also available as sodium, potassium or calcium salts. The advantages of salts over pure liquid acids are that salts are generally odorless and easier to handle in the feed manufacturing process owing to their solid and less volatile form. In addition, salts of organic acids are less corrosive and more soluble in water than most of the pure liquid acids. However, salt forms of acids do not have the potency to reduce the pH of the environmental because of the replacement in salts of the H⁺ ions by other cations such as Ca²⁺, Na⁺ and NH₄⁺.

**CHARACTERISTICS OF ORGANIC ACIDS**

Organic acids are widely distributed in nature as normal constituent of plants and animal tissues. They are also formed through omnipresent microbial fermentation. Organic acids produced by microbial fermentation in the digestive tract constitute an important part of the host animal, energy supply especially in ruminants.

The pKa value of organic acids varies between 3 and 6, as its particular values are presented in table 1. In general it can be stated that the lower the pKa value, the stronger the acid.

**EFFECTS ON HEALTH AND PERFORMANCE**

**Gastric pH**

As already stated dietary organic acids will reduced the pH of feed which in turn may reduce gastric pH. The hypothesis has been tested in several experiments with piglets. In most of these studies it was found that lowering dietary pH reduces gastric pH. However, only in a few studies the decrease in gastric pH could be marked as significant. Lowering the gastric pH of piglets through organic acids is of great importance, since the pH in the stomach of these animals is rather high. After feeding the gastric pH in young piglets might rise to 5-6.

### Table 1. pKa value of organic acids

<table>
<thead>
<tr>
<th>Compound</th>
<th>pKa¹</th>
<th>pKa²</th>
<th>pKa³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Formic acid</td>
<td>3.75</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Acetic acid</td>
<td>4.76</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Propionic acid</td>
<td>4.88</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Butyric acid</td>
<td>4.82</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Benzoic acid</td>
<td>4.19</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Lactic acid</td>
<td>3.86</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Sorbic acid</td>
<td>4.76</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Fumaric acid</td>
<td>3.02</td>
<td>4.38</td>
<td>-</td>
</tr>
<tr>
<td>Malic acid¹</td>
<td>3.40</td>
<td>5.10</td>
<td>-</td>
</tr>
<tr>
<td>Citric acid</td>
<td>3.13</td>
<td>4.77</td>
<td>6.40</td>
</tr>
</tbody>
</table>

¹ Fumaric and malic acid contain two and citric acid three H⁺-ions. Because of this, two or three pKa values are given for these acids.

### Table 2. The pH sensitivity of some bacteria

<table>
<thead>
<tr>
<th>Micromonism</th>
<th>pH value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clostridium perfringens</td>
<td>6.0 – 7.6</td>
</tr>
<tr>
<td>Escherichia coli</td>
<td>6.0 – 8.0</td>
</tr>
<tr>
<td>Pseudomonas aerogenes</td>
<td>6.6 – 7.0</td>
</tr>
<tr>
<td>Salmonella spp</td>
<td>6.0 – 7.5</td>
</tr>
<tr>
<td>Staphylococcus spp</td>
<td>6.8 – 7.5</td>
</tr>
</tbody>
</table>

**Source:** Johnston (1991)
Therefore, lowering the gastric pH of piglets with result in less optimal environmental conditions for the pathogenic microbes, because of their pH sensitivity (table 2). In addition, a reduced gastric pH will improve the activation of pensinogens which occurs rapidly at pH 2 and very slowly at pH 4 with no activity at pH 6 (Taylor 1959).

**Anti-microbial effects**

The anti-microbial activity of organic acids is affected by several factors including their pKa value, the environmental pH and the kind and quantity. The bactericidal effectiveness of organic acids were mainly studied in piglets. The published results indicate that with a dietary addition of organic acids the counts of Escherichia coli forms in the gastrointestinal tract can be reduced. In particular, this is true for formic and benzoic acid. In general a dietary addition of formic acid resulted in a decreased counts of Escherichia coli forms in the gastrointestinal tract of piglets (Bolduan et al 1988; Kirchgessner et al 1992; Cole et al 1992; Ludke and Schöne 1994). However, trends are found that dietary formic acid will also reduce the counts of lactobacillus in the ileal contents. Kluge et al (2006) reported that dietary levels of 0.5 and 1% benzoic acid reduced the number of bacteria in digesta of piglets. In the stomach the number of total aerobic, total anaerobic, lactic acid forming and gram negative bacteria was found to be reduced.

In the duodenum the presence of benzoic acid in the diet did reduce the number of gram-negative bacteria and in the ileum the number of total aerobic bacteria. The anti-microbial effects of benzoic acid in the gastrointestinal tract of piglets were confirmed in a study of Geggenbuhl et al (2007). These investigators reported that the counts of caecal Escherichia coli was significant reduced in piglets fed a diet supplemented with 0.5% benzoic acid.

In contrast to formic and benzoic acid the evidence for lowering the population density of coliforms in the gastrointestinal tract of piglets by adding fumaric acid, citric or propionic to piglets diets is rather weak. Some investigators reported that these acids had no effect on Escherichia coli population in the gastrointestinal tract (Risley et al 1992; Risley and Kornegay 1990; Mathew et al 1991; Sutton et al 1991). On the other hand some effects of these organic acids on Escherichia coli population in the stomach and small intestine were observed by other investigators (Isobe et al 1994; Cole et al 1968).

**Animal performance**

There is ample evidence that dietary inclusion of organic acids improves performance of young piglets as reviewed by Partanen and Mroz (1999) and Freitag et al (1998). However, the performance response to organic acids is highly variable. Partanen and Mroz (1999) reported that the growth response is closely related to change in feed intake, which alone would explain 74% of the variation.

The potential reasons for the highly variable results may be related to differences in type and dose level of the acid, composition of the diet, age of the animals, length of feeding period and the state of health of the animal. It has been suggested that improved palatability of a diet may be an important factor in the growth response of pigs to organic acids. However, this depends on the type and dose level of the acid. In general it can be stated that the acids, which are metabolized via the citric acid cycle (e.g. lactic, citric, fumaric acids) have a positive rather than a negative effect on food intake even at relatively high dose levels of 1%.

In growing pigs the response of organic acids on performance is less well pronounced than in piglets. Partanen and Mroz (1999) concluded on basis of a literature review that fumaric acid and formates are the most effective acids in promoting growth, followed by fumaric acid. Schutte (2005, 2006) reported that benzoic acid is also effective in promoting growth of pigs. In most studies a dietary addition of organic acids resulted in an improvement in feed conversion efficiency with no significant differences between acids. The feeding regimen (ad libitum or restricted) did not seem to influence the growth promoting effect of organic acids in growing pigs. However, some higher responses have been observed when pigs had free access to feed (Partanen and Mroz 1999).

**Other effects**

Partanen and Mroz (1999) concluded on basis of a literature review that organic acids may improve absorption and retention of Ca and P in pigs. Recently this was also proven by Sauer et al (2009) by including benzoic acid in the diet. In addition to an improved Ca and P retention also an improvement in protein digestibility was observed by including benzoic acid in pig diets.

It is suggested that organic acids will also improve the gut morphology. According to Pluske et al (1996) weight gain of weaned piglets is positively correlated with villous height. At weaning, the small intestine of piglets undergoes a reduction in villous height and an increase in crypt depth, which are associated with a decreased absorption capacity of the gut. Galli and Bokori (1990) observed that a dietary addition (0.17%) of Na-butyrate resulted in a substantial increase in the number of cells (33.5%) constituting microvilli, and in the length of micro villi (30.1%) in the ileum of growing pigs.

No information is available whether or not other organic acids will produce similar effects. However, it is well known that short chain fatty acids (acetic, propionic and n-butyric) produced by microbial fermentation of carbohydrates stimulate epithelial cell proliferation. Furthermore it is suggested that organic acids can influence the fermentation pattern by decreasing the concentration of ammonia, cadaverine or putrescine in the ileal digesta.

It is well known that inclusion of benzoic acid in diets of pigs results in a strong reduction of the pH of the urine and also in the slurry. This is due to the fact that benzoic acid is metabolized in the liver to hippuric acid which is excreted in the urine pathway (Bridges et al 1970). The latter results in a decreased urinary pH which in turn will decrease urease activity and ammonia emission. The results of several studies pointed out that dietary benzoic acid can reduce ammonia emission considerable in pigs. An example of one of these studies is presented in table 3. Compared to the control, a reduction of 25% was observed.
Table 3. Effect of graded dietary levels of benzoic acid on performance and ammonia emission in pigs (30-105 kg)

<table>
<thead>
<tr>
<th>Animal response</th>
<th>Benzoic acid, %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Daily weight gain, g/pig</td>
<td>813</td>
</tr>
<tr>
<td>Feed/gain ratio</td>
<td>2.80</td>
</tr>
<tr>
<td>Urinary pH</td>
<td>7.3</td>
</tr>
<tr>
<td>NH₃ emission, g/pig/day</td>
<td>8.1</td>
</tr>
</tbody>
</table>

Source: Schutte (2005)

CONCLUSIONS

It is considered that organic acids are used for many applications in human and animal nutrition. The use for the preservation of foodstuffs or single components is accepted all over the world as a very effective method to control growth of bacteria (Escherichia coli, Salmonella), mold and yeast. There is ample evidence that organic acids can improve performance of piglets and to a lower extent also those of growing pigs.

REFERENCES


