Use of organic acids in piglet diets: Learn more about the factors of choice of organic acids

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The use of organic acids in pig farming is not as a new technology: it was early found that piglets have difficulty in digesting diets containing vegetable proteins, mainly because of insufficient stomach acidification. However, we cannot say that this hypo-cloridorose features an immaturity in the digestive tract, since piglets and sows have evolved together over millions of years and their digestive tract is perfectly adapted to the digestion of sow milk. In nature weaning consists in a slow and gradual process, but with the development of industrial production we you now have a set weaning date and hour marked with purely economic interests. Over the years, the age at weaning has declined dramatically and a number of nutritional disorders have challenged veterinarians and nutritionists. Adverse effects of early weaning were so great that an reverse movement could be noticed. Below, we will highlight different aspects of the use of organic acids in the diets around and post weaning.

Technological evolution

Organic acids are substances widely distributed in nature: in plant and animal tissue constituents. They are also formed by fermentation of carbohydrates predominantly by microbial fermentation in the large intestine. From all the swine diets, the diet of piglets is by far the most complex, not only because of the number of ingredients, but also the number of parameters, which are not always very clear. The quality of ingredients has a big impact on the performance of piglets. The same ingredient with different industrial production process can strongly affect performance. As an example let’s take dairy products: different drying whey process may simply lead to a performance far from desired. The technology of using organic acids is well understood and they constitute an important tool for obtaining optimal performance. Over time, the organic acids are being increasingly studied in various aspects. Initially they were used in a simple way and in high doses to fulfill their role. This was possible as some acids are produced in large quantities, and identified in animal nutrition an application for venting large quantities available. Meanwhile, during this period, the salts of acids (especially calcium) were also the object of study. Subsequently, with the use of phosphoric acid, an inorganic acid only permitted for use in animal feed, it was possible to introduce acid blends with smaller inclusions and at more attractive prices. Comparative tables between acids, with chemical and physical parameters was the reference source for electing the “best” organic acids. The laws of dissociation x pKa pH of the medium, gain strength. “In vitro” tests have been proposed in order to find a way to compare them, including their dose. Later, these same tests proved not useful, since the dynamics of the acids in the digestive tract has played an important role in its effectiveness. In the digestive tract, the organic acids are absorbed and this is decreasing the importance of “in vitro” tests. The understanding of the use as a reducing agent of stomach pH and its antimicrobial action in the more distal portions of the intestine is definitely clear, so you cannot expect that no acid alone can act strongly in all categories, and therefore considered the best of all acids. Again, the tests “in vivo” were more promising and showed the need for the application of technologies in order that organic acids reach the more distal portions of the digestive tract in order to work with antimicrobial agents. Currently, film coated with fats, organic acids reach the more distal portions. After the action of lipase, the organic acids are released in satisfactory quantities. The emergence of new organic acids has highlighted the need of new methods on how to compare Organic Acids, as some may be insoluble in water, which reminds us of other concepts on acidic properties (Bronsted- Lowry and Lewis) that not only the traditional concept of Arhenius applies to water-soluble acids. Amidst this scenario, consumer pressure in some markets for the withdrawal of antibiotic growth promoters emphasizes...
the need to search for natural solutions to control and maintain the balance of intestinal flora. Of all solutions available at the time, the organic acids constitute not only the most promising but the most concrete although the MIC (minimum inhibitory concentration) is not entirely satisfactory. New technologies can and should arise to ensure MIC comparable to growth promoters.

Contributions in pig diets

The organic acids used in animal nutrition typically contain from 1 to 7 carbons. A range of roles and contributions can be assigned to organic acids. Evidently it cannot assign all of these properties to all acids. Some of them are remarkable in some acids, whereas the same property is absent in others. So there is not a perfect acid. It can be expected that an acid has a predominant or main action in addition to one or more side effects.

Relationship between the contributions that an organic acid may provide

• Reduction of the stomach pH;
• Decrease of intestinal transit time;
• Increase of the secretion of pancreatic enzymes;
• Modification of the gut microflora - antimicrobial agent;
• Reduction of the buffering capacity of the feed;
• Intermediate metabolite - as energy source;
• Improvement of performance – in weaning and fattening diets;
• Urinary pH reduction;
• Chelating agent;
• Energy source of the intestinal cell wall.


pKa and pH of the medium (dissociation laws)

The differences between the pH of the surrounding and the pKa of the organic acid govern how much of the acid will be in the un-dissociated form. pKa is defined as the pH at which the acid is 50% in the dissociated form and 50% in un-dissociated form. The latter is the way that the organic acid has its antimicrobial power. The organic acid may pass through the walls of bacteria and fungi only when it is in the un-dissociated form. Therefore, the lower the pKa of the organic acid, the greater is its effect on the reduction of stomach pH and the lower is its antimicrobial effect in the more distal portions during its transit through the digestive tract. However the pKa of organic acids is only one of the parameters of the choice of an acid. Among all the actions attributed to acids, we will focus on the two that are more common to all: reducing the buffering capacity of the feed and the antimicrobial properties.

Feed buffering capacity

Faced with the weakness of the hydrochloric acid production for vegetable protein digestion, a method to measure the buffering capacity of feeds and raw materials was created. In fact one can use one of two parameters: buffer capacity in milli-equivalents and called BValue which may be determined at pH 3, 4 or 5. It has been opted for 5 because it is faster and requires less acid for the titration during the analytical procedures. Over time, we tried to choose the optimum range of BValue to constrain our feed formulation. These parameters can be a trap. The final value can be great or ideal on average, but can be achieved with extreme alkaline raw materials and an acid. It seems more reasonable to use the BValue to select those raw materials which by nature are less alkaline; this is very important for the choice of mineral sources.

In the case of BValue at pH 5, it is known that the grains have a value slightly lower than 5, protein sources have value around 30 and 40 and the mineral sources between 240-1500 as is the case of dicalcium phosphate and calcium carbonate, respectively, as shown in Table 1.

Table 1. BValue pH 5 of raw materials

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>pH</th>
<th>B-Value pH5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn</td>
<td>6,1</td>
<td>3,50</td>
</tr>
<tr>
<td>Rice</td>
<td>6,5</td>
<td>2,80</td>
</tr>
<tr>
<td>Sorghum</td>
<td>5,9</td>
<td>5,00</td>
</tr>
<tr>
<td>Wheat</td>
<td>6,7</td>
<td>3,70</td>
</tr>
<tr>
<td>Barley</td>
<td>5,8</td>
<td>3,00</td>
</tr>
<tr>
<td>Triticale</td>
<td>6,8</td>
<td>7,00</td>
</tr>
<tr>
<td>Cassava</td>
<td>5,2</td>
<td>1,30</td>
</tr>
<tr>
<td>Potato Protein</td>
<td>5,4</td>
<td>3,00</td>
</tr>
<tr>
<td>Pea</td>
<td>6,5</td>
<td>11,00</td>
</tr>
<tr>
<td>Canola</td>
<td>5,3</td>
<td>6,80</td>
</tr>
<tr>
<td>Flaxseed</td>
<td>5,8</td>
<td>7,90</td>
</tr>
<tr>
<td>Soybean Meal</td>
<td>6,3</td>
<td>18,00</td>
</tr>
<tr>
<td>Meat and Bone Meal</td>
<td>6,3</td>
<td>32,00</td>
</tr>
<tr>
<td>Meat Meal</td>
<td>6,0</td>
<td>26,00</td>
</tr>
<tr>
<td>Whey</td>
<td>6,4</td>
<td>31,00</td>
</tr>
<tr>
<td>Dicalcium phosphate</td>
<td>7,3</td>
<td>248,00</td>
</tr>
<tr>
<td>Limestone</td>
<td>9,7</td>
<td>1750,00</td>
</tr>
</tbody>
</table>
It seems of little value to add an organic acid in the diet to counteract
the effect of calcium carbonate. It would be more meaningful to use a
more adequate source of calcium and to prioritize the use of organic
acid for other functions. Knowing the protein sources well is also
very important; for example plasma is a good source of protein, as
extra nutritional benefits are attributed to this feedstuff, thanks to
the presence of functional proteins, even though its B-Value value is high.
The same applies to milk proteins that are self-acidifying because of
its lactose content that turns into lactic acid. Ironically we can then
have a diet with high value B-Value, but being rich in plasma and milk
products, obtaining a great performance in comparison to a diet with
low B-Value and rich in organic acids, but also in soybean meal and
calcium carbonate. This reinforces the idea that this parameter has its
importance, but also has its limitations.

Antimicrobial effect

As we said at the beginning of the use of organic acids, we tried to
establish a hierarchy on their potential for microbial control with tests
in Petri dishes. As they do not consider the metabolism and its kinetic
in the digestive tract, the, these tests on the degree of dissociation
to gradual changes in pH do not necessarily reproduce the same
good results when tests are done in the field. A first step was made to
establish a hierarchy between an alkaline and an acidic pH, but the
dynamics of the absorption of the acid and the consequent reduction
of the concentration of acids in the digesta is missing. Furthermore,
the Petri dish method did not involve a population of micro-organisms,
but rather only one micro-organism, usually E. coli or Salmonella spp.
Walsh (2004) makes two quotations: in 2003, Mroz presented a review
with the following sequence of organic acids as potential “killer” of
Coliform - propionic less than formic <butyric <lactic <fumaric <benzoic.
He also mentions that in 2001, Jensen et al. demonstrated the
following sequence for control of Salmonella typhimurium at pH 4 in
gastric juice: acetic >formic >propionic >butyric >lactic >benzoic. A more
extensive and complex test was proposed by Knarreborg et al. in 2002
and completely changed the current anti-microbial action hierarchy.
This study evaluated the behavior of populations of bacteria against
different organic acids. This simulator proposed and presented a more
faithful reproduction of the dynamics happening in the digestive tract,
using different pH and culture media as well as anaerobic conditions.

In vivo tests are more appropriate but they should not only record the
performance, but include a number of parameters on the population
dynamics of the microbiota. With increasing restrictions on the use
of growth promoters, these studies should be improved to get closer
to reality, so that we better understand the dynamics of the microbiota.

Choosing an acid

You cannot completely separate each of the actions and contributions
of organic acids. The end result is nothing more than the sum of these
various actions (action on microbiota, performance and buffering
capacity) and then assess what is most important to choose the acid
to be used. Gheler et al. (2009) conducted a comparative study of
increasing doses of Benzoic acid (0.25%, 0.50%, 0.75% diets until 70
days) compared to a negative control and to a positive control with
fumaric acid (2%, 1.5%, 1% in the diet phase 1, 2 and 3, respectively).
The study was conducted in the experimental facilities of the University
of São Paulo, on the campus of Pirassununga. The results are shown in
Table 2.

Table 2. Results of experimental average daily feed intake (ADFI),
average daily gain (ADG), feed conversion (FCR) - 22-70 days.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>IW (kg)</th>
<th>FW(kg)</th>
<th>ADFI (g)</th>
<th>ADG (g)</th>
<th>FCR (g/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>6,968</td>
<td>30,656 c</td>
<td>987 c</td>
<td>564 b</td>
<td>1,75 a</td>
</tr>
<tr>
<td>0,25 % BzA</td>
<td>7,223</td>
<td>32,633 b</td>
<td>1,049 ab</td>
<td>605 ab</td>
<td>1,73 a</td>
</tr>
<tr>
<td>0,50 % BzA</td>
<td>7,27</td>
<td>33,352 b</td>
<td>1,052 ab</td>
<td>621 a</td>
<td>1,69 a</td>
</tr>
<tr>
<td>0,75 % BzA</td>
<td>7,375</td>
<td>34,171 a</td>
<td>1,092 a</td>
<td>638 a</td>
<td>1,71 a</td>
</tr>
<tr>
<td>Fumaric acid</td>
<td>7,134</td>
<td>31,158 c</td>
<td>1,002 b</td>
<td>572 b</td>
<td>1,75 a</td>
</tr>
</tbody>
</table>

Regression analysis:

<table>
<thead>
<tr>
<th>Effect</th>
<th>r2</th>
<th>CV (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ns</td>
<td>0.95</td>
<td>17,04</td>
</tr>
<tr>
<td>Linear</td>
<td>0.97</td>
<td>15,09</td>
</tr>
<tr>
<td>Linear</td>
<td>0.95</td>
<td>7,12</td>
</tr>
<tr>
<td>Linear</td>
<td>0.97</td>
<td>10,07</td>
</tr>
<tr>
<td>ns</td>
<td>0.97</td>
<td>9,43</td>
</tr>
</tbody>
</table>

BzA: benzoic acid
The methodology for determining the buffer capacity applied to organic acids contains a problem: the analytical procedures provide the acid dissolution in water. Benzoic acid being insoluble in water, the method does not seem suitable for the determination of this parameter. The benzoic acid in water forms a supernatant and therefore only some of it dissociates, providing a rather small contribution to the decrease of the solution pH. In addition, the pH is determined at room temperature and the benzoic acid is in liquid form at a temperature over 100°C. Such temperature is never achieved within the animal, but 40°C is quite feasible to achieve, which have a pH value changes significantly 3.02 to 2.80 as shown in the photo 2, 3, 4 and 5, respectively. It is noteworthy that the pH-meter is calibrated to 25°C, but what we want to highlight here is the downward movement of the values.

Although the values in Table 3 are affected by this technical difficulty for a correct determination of benzoic acid B-Value, it seems difficult to achieve equal B-Values as the ones achieved with fumaric acid. Another point is that even in experimental environment, ie with less challenge compared to field conditions, benzoic acid showed better gut-flora modulator properties, as shown in the control of diarrhea incidence in Table 4.

Table 3: Calculated B-Values

<table>
<thead>
<tr>
<th>Diet</th>
<th>Age</th>
<th>Control</th>
<th>BzA 0.25%</th>
<th>BzA 0.50%</th>
<th>BzA 0.75%</th>
<th>Fumaric acid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre Starter 1</td>
<td>22 a 35</td>
<td>16,57</td>
<td>15,75</td>
<td>14,93</td>
<td>14,11</td>
<td>-7,93</td>
</tr>
<tr>
<td>Pre Starter 2</td>
<td>36 a 46</td>
<td>17,52</td>
<td>16,70</td>
<td>15,88</td>
<td>15,06</td>
<td>6,27</td>
</tr>
<tr>
<td>Starter</td>
<td>47 a 70</td>
<td>34,64</td>
<td>33,82</td>
<td>33,00</td>
<td>32,18</td>
<td>27,14</td>
</tr>
</tbody>
</table>

Table 4: Control of diarrhea incidences

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Incidence of diarrhea</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>+</td>
</tr>
<tr>
<td>0,25 % BzA</td>
<td>+</td>
</tr>
<tr>
<td>0,50 % BzA</td>
<td>-</td>
</tr>
<tr>
<td>0,75 % BzA</td>
<td>-</td>
</tr>
<tr>
<td>Fumaric acid</td>
<td>+</td>
</tr>
<tr>
<td>BzA: benzoic acid</td>
<td>+</td>
</tr>
</tbody>
</table>

Conclusion

Reviews and previous comparisons between acids looking at the criteria Buffering capacity may lead to erroneous conclusions. The buffering capacity has been used as a criterion for selection of organic acids from the beginning of its use and it is time to extend this vision. The use of acid mixtures is common, but their compositions have been established much more due to a price objective than based on solid technical proofs. These mixtures show variable levels of calcium and phosphorus, indicating that what is presented as an acid, is actually present as the calcium salt of the parent acid. The salts have a lower antimicrobial activity than the original acid, and this is remarkable for divalent salts as calcium because they do not contain the hydrogen to dissociate the bacterial cytol. The results of the experiment Gehler, R.T. et all (2005) show that the antimicrobial action exerted by the benzoic acid is much more important than the lowering effect of dietary buffering capacity. Thus, it can be concluded that the exclusive use of benzoic acid becomes economical to the extent their use is not necessary to use mixtures of organic acids based on their theoretical reduction of buffering capacity and stomach pH.

The stomach acidification and antimicrobial functions in the intestine are diametrically opposed by the dissociation laws. Blends or mixtures of acids focused on acidification in the stomach have a well-established position, but we must observe and check their composition to see if every ingredient is in fact dedicated to this purpose. The use of organic acids with intestinal antimicrobial agent is dependent on the application of technologies to ensure the release of amounts acceptable in the important distal part of the digestive system (higher pKa). The degree of insolubility is another way to ensure that large amounts of acid reach more distal portions of the intestine, such as benzoic acid. It is also known that some organic acids can contribute to the restoration and preservation of the intestinal wall. New technologies must be generated so that the MIC values are comparable to antibiotic growth promoters (AGP).
References


3 – MARION J. et al. (2002). Effects of weaning at 7 days of age and the level of energy intake on structural changes in the small intestine of piglets. Journées de Recherche Porcine, 34: 89-95


6 – Knarreborg A. et al, (2002). Establishment and application of an in vitro methodology to study the effects of organic acids on coliform and lactic acid bacteria in the proximal part of the gastrointestinal tract of piglet. Animal Feed Science and Technology 99 131-140