

Principles of using organic acids in animal nutrition

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Introduction

Following the European ban of antibiotic growth promoters (AGPs) in 2006, the use of organic acids in animal nutrition has gained significant importance in the feed industry. Their positive effects on feed quality and animal performance have been known for decades and, as they increasingly capture the attention of the feed industry, there is a growing need to define the several acids and their salts as well as to distinguish between their strengths and weaknesses.

What are organic acids?

The term 'organic acids' refers to all those acids built on a carbon skeleton, known as carboxylic acids, which can alter the physiology of bacteria, causing metabolic disorders that prevent proliferation and cause death.

Almost all the organic acids used in animal nutrition, such as formic, propionic, lactic, acetic, sorbic or citric acids have an aliphatic structure and represent a source of energy for the cells. Benzoic acid, instead, is built on an aromatic ring and has different metabolic and absorption characteristics.

The supplementation of organic acids at the right high doses in animal feed can increase the bodyweight, improves feed conversion ratio and reduces colonization of pathogens in the intestine. Specifically, Kirchgessner and Roth (1988) differentiate between different actions, including:

- Decrease of pH value and the buffering capacity as well as antibacterial and antifungal effects in the feed;
- Reduction of pH value by release of hydrogen ions in the stomach, thereby activating pepsinogen to form pepsin and improving protein digestibility;
- Inhibition of gram-negative indigenous microflora in the gastro-intestinal tract;
- Improved energetic utilization in the intermediate metabolism.

The efficiency of an organic acid to inhibit the growth of a microorganism depends on its pKa value, which describes the pH value at which the acid is available 50% in its dissociated and un-dissociated form respectively. Only in its un-dissociated form the organic acid has its antimicrobial power as they can pass through the walls of bacteria and fungi and alter their metabolism. This means that the antimicrobial efficacy of organic acid is higher in acidic conditions, like in the stomach, and reduced at neutral pH, like in the intestine. Accordingly, organic acids with a high pKa value are weaker acids and therefore more effective preservatives for feed, as, being present in the feedstuff with a higher proportion of their un-dissociated form, can defend feed from fungi and microbes. (Roth and Eittle, 2005). Therefore, the lower the pKa of the organic acid (the higher proportion of dissociated form) the greater is its effect on the reduction of stomach pH and the lower its antimicrobial effect in the more distal portions during its transit through the digestive tract. A strong acid (with low pKa) will acidify the feed and the stomach, but will not have strong direct effects on the microflora in the intestine.

Table 1: Chemical and physical characteristics of selected organic acids (Kirsch, 2010)

Acid	Molar mass [g/mol]	Density (g/ml)	Physical state	pKa
Formic	46.03	1.220	liquid	3.75
Lactic	90.08	1.206	liquid	3.83
Acetic	60.05	1.049	liquid	4.76
Sorbic	112.14	1.204	solid	4.76
Propionic	74.08	0.993	liquid	4.88
Benzoic	122.12	1.270	solid	4.20

This is one of the reasons why acids like propionic acid, with a high pKa value, are mainly used as preservatives for grain or feed and less for impacting the animal performance directly, whereas formic or lactic acid are mainly used to improve digestibility processes. Additionally, there are some specific effects against yeasts, moulds and bacteria of each acid, which cannot be explained by the pKa value. Strauss and Hayler (2001) marked differences in the inhibitory effect of several organic acids on bacteria (Table 2).

Table 2: Minimal inhibitory concentration (MIC) of different organic acids

	Formic acid [%]	Propionic acid [%]	Lactic acid [%]
Salmonella typhimurium	0,10	0,15	0,30
Escherichia coli	0,15	0,20	0,40
Campylobacter jejuni	0,10	0,20	0,25
Staphylococcus aureus	0,15	0,25	0,40
Clostridium botulinum	0,15	0,25	0,30
Clostridium perfringens	0,10	0,25	0,30

The MIC values in Table 2 reflect the activity of different organic acids against gram-negative and gram-positive bacteria determined under in vitro conditions.

A research study by Strauss and Hayler (2001) on lactic acid showed that low concentrations of applied acid can lead to the stimulation of growth of Clostridium perfringens when lactic acid was used at a dosage below 0.20%.

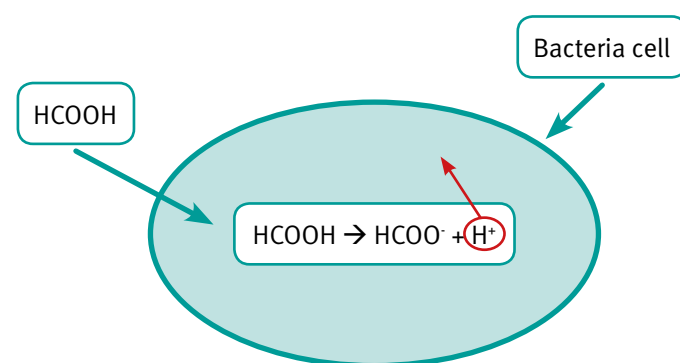
Other authors found enhanced development and increased mycotoxin formation when propionic, benzoic and sorbic acids were used at sub-inhibitory concentrations (Müller et al., 1981, Uraih et al., 1977, Spicher and Westenhoff, 1985).

Formic acid is not suitable to suppress moulds in compound feeds or grain as it may promote the growth of aflatoxin-forming Aspergillus species (Petterson et al., 1989). Thus, its use to treat aerobically stored high-moisture grains is prohibited in the EU if the additive contains >50% of formic acid.

In general, considerably higher dosages - depending on species - are needed in animal feed to get measurable effects on animal performance, because under in vivo conditions factors such as crude protein content, total buffering capacity, environmental conditions and age and health status of the animals play an additional influencing role.

Mode of action

The antimicrobial activity is caused by the ability of organic acids to dissociate (Partanen 2001). In the un-dissociated form, acid molecules can easily penetrate the microbial cell walls of gram-negative bacteria. Inside the cell the pH is higher than its pKa and a large proportion of the acid will dissociate and release its hydrogen ion (H+). In the attempt to pump out the hydrogen ions (H+), the microbial cell consumes enormous amounts of energy that lead to cell death (Figure 1).

**Figure 1:** Antimicrobial effects of organic acids

To maximize the direct effect of organic acids against pathogens, it is a precondition that the acid molecule and the pathogenic microorganism get in contact. This means that the active ingredient of an organic acid has to reach the place where pathogens are located, which could either be the feed or the stomach, but in most cases it is the intestinal tract. Bacteria like *E. coli* and *Salmonella ssp.* are located in the small intestine. Under in vivo conditions and by using a practical dosage of 5 kg liquid formic acid (85% active ingredient) per ton of compound feed, Kirsch (2010) only found 5.5% of the active ingredient in the small intestine.

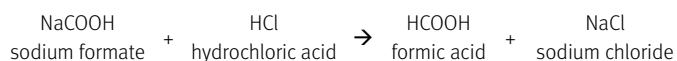
Similarly, Maribo et al. (2000a) only detected 4.4% of active ingredients in the small intestine by using a dosage of 0.7% liquid formic acid in the diet. She tested as well benzoic acid by using 2% benzoic acid in the first piglet diet (week 4-6) and 1% benzoic acid in the second piglet diet (week 6-10). She found a much higher level in the intestine as 22% of benzoic acid was found in the last third of the small intestine (Maribo et al. 2000b).

Salt or acid?

All pure liquid organic acids are corrosive products. Even if these liquid acids are sprayed on a carrier, the product can be corrosive - depending on the active ingredients-. Salts of organic acids, like calcium propionate, sodium formate or sodium benzoate seemed a good option to add active ingredients in a solid and non-corrosive form. The use of organic acid salts represents a nice tool given that the concentration of cations (e.g. Ca^{2+} , Na^{+}) added by the salt is considered in the diet formulation, thereby reducing the buffering capacity of the compound feed.

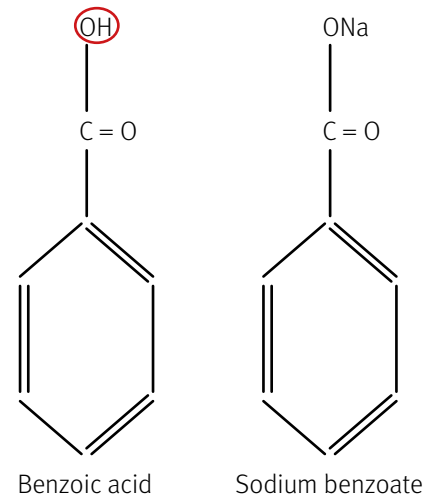
However, the mode of action of organic acids (Figure 1) depends on free hydrogen ions to activate the organic molecule into the dissociated or un-dissociated form respectively. Unlike organic acids, salts do not have an hydrogen ions to release.

The chemical fact: "the stronger acid releases the weaker one from its salts" is still valid and can be illustrated by the following reaction:



Once the salts reach the stomach, the acid pH triggers a reaction that transforms them into acids where hydrochloric acid is needed to release the formic acid from the sodium formate. In swine nutrition this will improve digestibility in the stomach of adult monogastric animals better than in younger animals, whose stomach produce less HCl.

To achieve a direct acidifying effect by applying organic acids salts is indeed not possible.



Only the H^{+} is responsible for an acidifying effect

Conclusion

The pKa value of an organic acid is responsible for its inhibiting effects on microorganisms. The effect of organic acids is in general dose-dependent, the more active ingredients reach the site of action, the higher will be the desired effects. This is valid for both the preservation of feed and the nutritional and health effects in the animal. Salts of organic acids can help to reduce the buffering capacity of the feed and can deliver an anion for organic acid production, in case a stronger acid is present; however, the salts themselves will not have any acidifying effect.

The list of references will be provided by the author upon request.

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