Journal of Cell and Animal Biology Vol. 6(10), pp. 154-159, 31 May, 2012
Available online at http://www.academicjournals.org/JCAB
DOI: 10.5897/JCAB11.081
ISSN 1996-0867 ©2012 Academic Journals

Review

The use of organic acids in monogastric animals (swine and rabbits)

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Accepted 28 May, 2012

The risk of bacteria acquiring resistance to specific antibiotics led to a ban of antibiotics as growth promoters in European Union (EU) since January 2006. In recent decades, organic acids (acidifiers) have been used as potential alternatives to antibiotics in monogastric animals' diets in order to improve growth performance and prevent diseases. The probable mode of actions of organic acids includes reducing the digesta pH value in the gastrointestinal tract (GIT), regulating the balance of microbial populations in the gut, stimulating the secretion of digestive enzyme and promoting the growth and recovery of the intestinal morphology. Moreover, acidifiers appear to have antimicrobial activity, by controlling the bacterial populations in the gut, increasing activity of proteolytic enzymes, and inhibiting the proliferation of pathogenic bacteria. Dietary organic acids can actually become an alternative solution to antibiotics, in order to improve health status and performance in livestock. The purpose of this review is to summarize the beneficial effects of using organic acids in monogastric (pig and rabbit) animals' diets.

Key words: Acidifiers, organic acids, effect, growth performance, health status, pig, rabbit.

INTRODUCTION

Antibiotics have been successfully used in animal production since their discovery for maintaining health and improving performance. However, the risk of bacteria acquiring resistance to specific antibiotics and antibiotic residues in meat led to a ban of antibiotics as growth promoters in European Union (EU) since January 2006. With increasing pressures of antibiotic resistance and food safety concerns, acceptance for the use of non-therapeutic antibiotics in animal feed is eroding in the EU countries (Doyle 2001). Organic acids are routinely included in diets for monogastric animals in Europe as a preservative and acidifier, in order to replace antibiotics as growth promoters and prevent or control pathogens.

As a group of chemicals, organic acids are considered to be any organic carboxylic acid of the general structure R-COOH (including fatty acids and amino acids). Not all of these acids have effects on gut microflora. Organic acids with specific antimicrobial activity are short-chain acids (C1–C7) and they are widely distributed in nature as normal constituents of plants or animal tissues. They are also formed through microbial fermentation of carbohydrates mainly in the large intestine. They are sometimes found as their sodium, potassium or calcium salts. Most organic acids with antimicrobial activity have a pKa— (the pH at which the acid is half dissociated)- between 3 and 5. Table 1 shows the common name, chemical name, formula and first pKa of organic acids that are commonly used as dietary acidifiers in monogastric animals (Dibner and Buttin, 2002).

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ORGANIC ACIDS IN MONOGASTIC ANIMALS' DIET

Several organic acids have been reported to improve growth performance (for example, increased palatability, feed efficiency, mineral absorption, phytate-P utilization)

Table 1. List of organic acids and their properties, list of acids and their properties used as dietary acidifiers for pigs or poultry.

Acid	Chemical name	Formula	pKa
Formic	Formic acid	$HCOOH$	3.75
Acetic	Acetic acid	CH_3COOH	4.76
Propionic	2-Propanoic acid	CH_3CH_2COOH	4.88
Butyric	Butanoic acid	$CH_3CH_2CH_2COOH$	4.82
Lactic	2-Hydroxypropanoic acid	$CH_3CH(OH)COOH$	3.83
Sorbic	2,4-Hexandienoic acid	$CH_3CH{:}CHCH{:}CHCOOH$	4.76
Fumaric	2-Butenedioic acid	$COOHCH{:}CHCOOH$	3.02
Malic	Hydroxybutanedioic acid	$COOHCH_2CH(OH)COOH$	3.40
Tartaric	2,3-Dihydroxy- Butanedioic acid	$COOHCH(OH)CH(OH)COOH$	2.93
Citric	2-Hydroxy-1,2,3- Propanetricarboxylic acid	$COOHCH_2C(OH)(COOH)CH_2COOH$	3.13
Benzoic	Benzenecarboxylic acid	C_6H_5COOH	4.19

when they are supplemented in non ruminant diets (Partanen and Mroz, 1999; Dibner and Buttin, 2002; Boling et al., 2001). In addition, organic acids are believed to have antimicrobial activity and they have been suggested for the control intestinal microbial growth (Partanen and Mroz, 1999; Davidson, 2001). The antimicrobial activity of organic acids is basically the same, irrespective of acting in food, feed, or gut lumen (Diebold and Eidelsburger, 2006). Most available information about the use of acidifiers in animal feeding is focused on swine and poultry (Partanen and Mroz, 1999; Dibner and Buttin, 2002).

Several mechanisms through which dietary organic acids may produce beneficial effects on health status and growth performance have been proposed (Partanen and Mroz, 1999; Partanen, 2001; Knarreborg et al., 2002; Diebold and Eidelsburger, 2006; Tung and Pettigrew, 2006), however the following appear to be the most prominent:

1) Reduction of gastric pH
2) Reduction of buffering capacity of diets
3) Increase of proteolytic enzymes activity / Improvement of pancreatic secretions
4) Stimulating the activity of digestive enzymes
5) Increase of nutrient digestibility
6) Promotion of beneficial bacterial growth
7) Reduced survival of pathogens through the stomach / balancing the microbial population
8) Direct killing of bacteria
9) Alterations in the nutrient transport and synthesis within the bacterium
10) Depolarization of the bacterial membrane

Considerable variations in the results of their response due to possible dietary and other factors such as: type and pKa of acid, inclusion rate and dose of supplemented acids, type / composition of diets and their acid-base or buffering capacity, level of intraluminal production of acids in gastrointestinal (GI) tract by inhabiting microflora, feed palatability, intrinsic acid activity, receptors for bacterial colonization on the epithelial villi, maternal immunity by vaccinations against pathogens, hygiene and welfare standards and age of animals (Partanen and Mroz, 1999; Strauss and Hayler, 2001; Decuypere and Dierick, 2003; Morz, 2005).

Beneficial effects of organic acids on swine

Benefits from the use of dietary acidifiers include positive effects on growth performance and health status (Table 2). The organic acids have antimicrobial effects, which vary from one acid to another, depending on concentration and pH (Chaveerach et al., 2002). For example, lactic acid is more effective in reducing gastric pH and coliforms (Jensen et al. 2001; Tsiloyiannis et al., 2001a; Øverland et al., 2007), whereas other acids, such as formic, propionic have broader antimicrobial activities and they can be effective against bacteria (for example, coliforms, clostridia, Salmonella), fungi and yeast (Partanen and Mroz, 1999; Bosi et al., 2005; Creus et al., 2007; Øverland et al., 2007). Several reports have shown that the use of organic acids may reduce the coliform burden along the gastrointestinal tract) and reduce scouring and piglet mortality or control post weaning diarrhea and edema disease in piglets (Tsiloyiannis et al., 2001a, 2001b; Piva et al., 2002a, Papatsiros et al., 2011). Acidifiers have received much attention in pig production due to their beneficial effects on growth performance of pigs (Mahan et al., 1996; Partanen, 2001; Papatsiros et al., 2011). The beneficial effects of organic acids and their salts on growth performance have been confirmed in several studies. Acidifiers added to pig diets may potentially help improve growth performance (Table 2) by improving digestive processes through several

Table 2. Beneficial effects of most common acids in swine.

Acid	Beneficial effects	
	Antimicrobial activity	Improvement of growth performance
Formic	*E. coli , Salmonella spp.* Creus et al. (2007), Jensen et al. (2001), Knarreborg et al. (2002), Naughton and Jensen (2001), Øverland et al. (2007) and Tsiloyiannis et al. (2001a)	Canibe et al. (2005), Jongbloed et al. (2000), Mroz, et al. (2000), Partanen et al. (2001a,b, 2007), and Tsiloyiannis et al. (2001a), Cesari et al. (2008)
Acetic	*E. coli , Salmonella spp.* Jensen et al. (2001) Partanen and Mroz (1999)	Piva et al. (2002) and Valencia (2002)
Propionic	*E. coli , Salmonella spp.* Jensen et al. (2001), Knarreborg et al. (2002), Naughton and Jensen (2001) and Tsiloyiannis et al. (2001a)	Partanen et al. (2007) and Tsiloyiannis et al. (2001a)
Butyric	*E. coli.* Knarreborg et al. (2002) and Naughton and Jensen (2001)	Mroz et al. (2000)
Lactic	*E. coli , Salmonella spp. - moulds and yeasts* Creus et al. (2007), Jensen et al. (2001), Naughton and Jensen (2001), Piva and Grilli (2007) and Tsiloyiannis et al. (2001a, b)	Jongbloed et al. (2000), Tsiloyiannis et al. (2001a, b), Cesari et al. (2008)
Sorbic	*E. coli, Salmonella spp. - yeasts, moulds, fungi* Jensen et al. (2001), Øverland et al. (2007) and Piva and Grilli (2007)	Kirchgessner et al. (1995)
Fumaric	*E. coli , Clostridia)* Biagi et al. (2003), Knarreborg et al. (2002), Naughton and Jensen (2001) and Tsiloyiannis et al. (2001a), Abecia et al. (2005)	Giesting et al. (1991), Mroz et al. (2000) and Tsiloyiannis et al. (2001a), Castrovilli (1991), El-Kerdawy (1996), Hullar et al. (1996), Zi Lin et al. (1996)
Malic	*E. coli, yeasts* Partanen and Mroz (1999), and Tsiloyiannis et al. (2001a)	Kirchgessner et al. (1993), and Tsiloyiannis et al. (2001a)
Citric	*E. coli* Foegeding and Busta (1991), Tsiloyiannis et al. (2001a, b)	Boling et al. (2000) and Tsiloyiannis et al. (2001a, b)
Benzoic acid	*E. coli, Salmonella spp.* Papatsiros et al. (2011) and Piva and Grilli (2007)	Kluge et al. (2006) and Maribo et al. (2000)

mechanisms. They can improve gut health by promoting the beneficial bacterial growth, while inhibiting growth of pathogenic microbes (through reduction of pH and buffering capacity of diets). A reduced buffering capacity of diets containing organic acids is also expected to slow down the proliferation and/or colonization of undesirable microbes, for example, *E. coli, clostridia*, *salmonella spp*. in the gastro-ileal region (Partanen and Mroz, 1999; Biagi et al., 2003). Organic acids can also stimulate pancreatic secretions (Harada et al., 1986), which increase the digestibility, absorption and retention of protein and amino acids (Blank et al., 1999; Kemme et al., 1999) and minerals (such as Ca, P, Mg and Zn - particularly Ca and P) (Jongbloed et al., 2000; Valencia, 2002) in the diet.

Beneficial effects of organic acids on rabbits

The mucosa of the small intestine has a major role in the digestion and absorption of nutrients and represents an important area of defence against antigenic aggressions in young rabbits (Gallois et al., 2005). The use of organic acids appears interesting, even though scientific data concerning their effect on microflora population, mucosal immunity and growth performance are few and often contradictory in rabbits (Falcao - e - Cunra et al., 2007). The mode of action of these products on caecal microflora is not also completely understood, although it is demonstrated that organic acids play a direct action on the bacterial cell integrity (Maertens et al., 2006).

The effects on digestibility and productive performances due to inclusion of organic acids in rabbit nutrition are not completely clear. Improvements in daily gain have been reported in many studies, but no effects were recorded by others (Hollister et al., 1990; Scapinello et al., 2001). In addition, antimicrobial activity of organic acids in rabbits has also been reported (Skřivanová and Marounek, 2002), reducing the damage caused by both Gram-negative and Gram-positive bacteria (Cardinali et al., 2008). In contrast, in other studies testing sodium butyrate (Carraro et al., 2005) and fumaric acid (Scapinello et al., 2001) or formic acid (Skřivanová and Marounek, 2007) no antimicrobial activity was indicated.

CONCLUSION

Modern animal production is trapped between consumer's concerns on animal and human health and an increasing demand for animal products. Nowdays, there is an increased public awareness about the risk of developing cross-resistance of pathogens to antibiotics (Corpet, 1996; Mathew et al., 2007; Hunter et al., 2010). To overcome the ban on antimicrobial growth promoters in Europe alternatives are needed to maintain high productivity. A promising approach in pig and rabbit nutrition is the use of organic acids. Digestive disorders constitute the main health problem in weaned piglets and rabbits and antibiotics are widely used for prevention of infections and as a growth promoter, altering the gut flora, suppressing bacterial catabolism and reducing bacterial fermentation (Partanen, 2001; Papatsiros et al., 2011; Pinheiro et al., 2004). As the use of organic acids are becoming better accepted by feed manufacturers, animal producers and public, there is a developing interest in substituting them as an efficacious alternative solution to antibiotics, in order to improve health status and growth performance in swine and rabbits.

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