ORGANIC ACIDS AS FEED ADDITIVE IN PIG AND POULTRY DIETS: A REVIEW

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ABSTRACT
A review was carried on the potentials of organic acids as feed additive in the diets of poultry and pigs. Organic acids (as acetic, butyric, citric, formic and propionic acids) or their salts (calcium formate and sodium butyrate) are weak carboxylic acids that occur naturally in fruits but could be synthesized and manufactured in commercial quantity. They exhibit certain properties which could make them unique as growth promoters in monogastric animals. Organic acids are antimicrobial in action reducing bacteria and fungi both in the feed and in the gastro intestinal tract. Their ability to reduce gram negative pathogenic bacteria in the gut reduces fermentation in the gut thereby improving digestibility, nutrient absorption and utilization. Other areas organic acids could enhance animal productivity is their ability to induce endogenous secretions such as gastric hydrochloric acid, enzymes, bile and mucus. They also function to increase the number and height of the villi and reduce both the crypt depth and digesta viscosity. High level in the feed could reduce feed intake and growth. They could be corrosive to feed mixers, feed bins, silos, feeding and could also pose health problems to farm and feed mill attendants.

Keywords: feed additive, pig, poultry, and organic acids.

INTRODUCTION
One of the nutritional strategies to enhancing the rapid growth of monagastrics had been the addition of feed additives (Windisch, *et al*., 2007). Formulating a diet for monogastric animals for its effect on gut health and functions is important for nutrient uptake and utilization for adequate growth (Choct, 2009). Sequel to this, substances that could positively modulate the micro-flora are used as additives to serve as digestion and nutrient absorption enhancers thereby promoting growth. Mohan *et al*. (1996) noted that growth promoters or stimulants are important feed additives for improving growth rate, feed efficiency and prevention of intestinal infections. Such growth promoters (pharmaceutical antibiotics, enzymes, hormones, arsenicals, copper and zinc) have been reported to have positive effect nutritionally. Among these feed additives pharmaceutical antibiotics were commonly used (Maynard *et al*., 1981; Patterson and Burkholder, 2003; Al Harthi, 2006; Banerjee. 2007; Abaza *et al*., 2008). Pharmaceutical antibiotics are antibacterial compounds produced by microorganisms such as penicillin, streptomycin and chloramphenicol (Dibner, 2004).

But recent concerns about the antibiotics resistance and toxicity of other feed additives in livestock industry have prompted the need for alternative strategies to improve animal performance and health without the use of such antibiotics (Chen *et al.*, 2005). Some dietary products such as probiotics (Cheeson, 1994), prebiotic (Patterson and Burkholder, 2003), yeast culture (Gao *et al.*, 2008), essential oils and spices (Windisch *et al*., 2007) are therefore being evaluated to replace antibiotics in poultry diets. Organic acids were reported to improve productivity of pigs and poultry (Leeson *et al.*, 2005; Mroz *et al*., 1997; Paul *et al*., 2007; Ndelekwute *et al*., 2010; 2011b). Organic acids (acetic, butyric, citric, formic and propionic acids) or their salts (calcium formate and sodium butyrate) are weak carboxylic acids. They have been used for decades in feed preservation, protecting feed from bacterial and fungal destruction (Paul *et al.*, 2007). They occur naturally mostly in fruits amd are also manufactured in commercial quantity using hydrocarbons. The potentials of organic acids to support growth of monogastrics has been reported to be due to their antibacterial effect and stimulation of villi growth (Leeson *et al*., 2005). The objective of this review was to look at the potentials as feed additives.

OVERVIEW OF ORGANIC ACIDS

Acids in general are chemical compounds that can donate proton (H^+) to another compound. This is called Bronsted definition of acids (Conn and Stumpf, 1976). In terms of presence of carbon, acids are classified into organic and inorganic acids. Inorganic acids (mineral acids) do not contain carbon and include hydrochloric, sulphuric, phosphoric and nitric acids. Organic acids such as acetic, butyric, citric, formic and lactic acids contain carbon and a carboxyl group with the general formula R–COOH. (Dibner, 2004) as shown in Table 1. According to Brown (1981) organic acids are further divided into aliphatic monocarboxylic acids (acetic, butyric, formic and propionic acids) containing one carboxyl (COOH) group, aliphatic dicarboxylic acid (oxalic and malonic acids) having two carboxyl (COOH) groups and aliphatic tricarboxylic acids (citric acid) with three carboxyl (COOH) groups.

Although both organic and inorganic acids can donate protons, they do not behave similarly in aqueous solution. While mineral acids are almost completely dissociated in solution, organic acids are only partially dissociated and hence are called weak acids (Kuchel *et al*., 1988). The strength of organic acids (weak acids) is determined by the concentration of the proton (H^+) in solution expressed as Ka, known as the dissociation constant. Each organic acid has a particular pH at which it is partially dissociated called the pKa. The lower the pKa, the stronger the acid (Kuchel *et al*., 1988). Similarly, as pH is the negative log of hydrogen ion concentration (- Log H^+), pKa is the negative log of dissociation constant (- log Ka).

Sources of Organic Acids

Brown (1981) reported that organic acids could be obtained in nature from both plants and animals. Formic acid is obtained from ant, acetic acid from vinegar and citric acid from citrus species. They occur naturally in fruits, especially the unriped ones (Table 2). These acids are responsible for the sourness of unriped fruits. During ripening, the concentration of the acids decreases and that of sugar increases. The taste of acidity in fruits depends very much on the sugar: acid ratio and the buffer effects of salts, proteins and fats Brown (1981). Aliphatic organic acids occur in citrus, pineapple, tomato; malic acid in tomato, apple; oxalic acid in unriped tomatoes, strawberries; and tartaric acid in grapes. Aromatic organic acids such as benzoic acid, quinic acid, Shikimic acid and chlorogenic acid also occur in fruits. Other sources of organic acids are ant which has formic acid and vinegar which contains acetic acid. According to Brown (1981) organic acids could be manufactured industrially using hydrocarbons.

Antibacterial Actions of Organic Acids

Studies have shown that utilizing butyric and lactic acids reduced cecal colonization of broilers by *Salmonella typhimurium* at 14 and 21 days of age (Hinton *et al*., 1985; McCubbine, 1989; Mchan, 1992). In contrast, Waldroup *et al*. (1995) opined that feeding organic acids (lactic, formaric and citric acids) to broilers was not a reliable means of reducing *salmonella* colonization.

The antibacterial effect of organic acids has been explained to be as a result of decreased pH in addition to specific antibacterial effects of the undissociated acid molecule in the gut when organic acids were fed (Debevere, 1987; Smulders, 1987). According to Waldroup *et al*. (1995), undissociated acid molecules enter bacteria cells and dissociate into anions ($R–COO^-$) and protons (H^+) which cause the pH of the cytoplasm to decrease, limiting synthesis of several macromolecules that includes cell wall components, DNA, lipids, proteins and RNA. Apparently, destruction of bacteria is not by lysis or perturbation of the cell membrane but by inability of the bacteria to replicate rapidly (Paul *et al*., 2007). Earlier, Cherrington *et al*. (1991) had considered bacteria destruction to be by cell destruction. Canibe *et al*. (2008) had reported that increase in the concentration and carbon chain length increases the antimicrobial effect of organic acids. Nevertheless, certain bacteria cells resist diffusion or attack of organic acids Russell and Diez-Gonzallez (1998). Lactic acid bacteria are able to grow at relatively low pH, suggesting that they are more resistant to organic acids than other bacteria species (Paul *et al*., 2007). Russell and Diez-Gonzallez (1998) explained this to be that gram positive bacteria have a high intracellular K^+ concentration, which provides a counteraction for the acid anions.

It is possible that this is not only applicable to gram positive micro-organisms and that certain gram negative microorganisms such as *salmonella typhimurium* adopt some strategies to resist acid medium and adapt to it (Kwon and Ricke, 1998). This phenomenon is known as inducible acid tolerance (IAT). Inducible tolerance (adaptation) to acidic environment according to Canibe *et al*. (2008) is recognized as an important survival strategy for many prokaryotic and eukaryotic microorganisms. According to Canibe *et al*. (2008) advances in understanding this phenomenon include the identification of regulatory, as well as structural genes involved in specific tolerance mechanisms. Under threat by acid, they would sense an uncomfortable environment and undergo programmed molecular responses during which specific, stress-inducible proteins are synthesized (Canibe *et al*., 2008). The duty of these proteins is to prevent or repair macromolecular damage caused by the acid. Some stress proteins are induced by a range of stress conditions, while others are induced in response to specific stress (Bearson *et al*., 1997). In addition, different microorganisms have developed different IAT strategies (Lin *et al*., 1995). Bearson *et al*. (1997) reported that there is a correlation between the response of entero-bacteria to acid stress and pathogenecity.

Dietary organic acids added to feed or water exert their actions exogenously (in feed and water) and endogenously (in the gut). The salts of organic acids such as calcium formate and sodium propionate acidify only the gut and are hus called gut acidifiers (Paul *et al*., 2007). Organic acids are used to prevent microbial growth in feed and to sanitize drinking water for birds (Phillipsen, 2009).
The reports of Chaveerach *et al*. (2004) revealed that short chain acids (SCAs) are potential inhibitors of *campylobacter spp* in water. The same SCAs have been widely used to prevent pathogenic bacteria in food products (Van Nethen *et al*., 1994). Acid from lime juice has been identified as having biocidal effect in drinking water contaminated with *vibrio cholerae* (Dalsgaard *et al*., 1997).

Negative effect on the health of the animal has not been reported. However, organic acids such as acetic and citric acids are intermediaries in metabolic processes of the body.

B -Value of Organic Acids
The ability of diet treated with organic acids to reduce the pH of the stomach depends on the B-value. The B-value of an organic acid (binding capacity) is the amount of the acid needed to lower the pH of a feed or feedstuff to a certain level (Makkink, 2001). The B-value is often expressed as the quantity in milliequivalent (MEq) of 1.0M HCl required to acidifying 1.0 kg of the feed or feedstuff to a pH of 3-5. Different feed materials have different characteristic B-value (Table 3). Protein feedstuffs (soyabean meal, fish meal and milk powder), mineral feed ingredients (calcium carbonate, bone meal) and premixes because of $CaCO_3$ content used as a carrier, have high B-value while cereals (maize, sorghum and wheat) have low B-value.

According to Makkink (2001), it is possible to calculate a composite B-value of a feed from the B-values of the ingredients that make up the feed by using an endpoint of pH = 5 to determine the B-value of each ingredient. With pH = 5, the B-value of the feed ingredients becomes additive. When using a lower endpoint (e.g. pH = 3 or 4) the B-Values are no longer additive. However, Makkink (2001) warns that because the B-value of feedstuffs varies with batches, using ingredient B-value from tables become unrealistic.

The B-value in pig and poultry feeds is important because low pH is required in the stomach of the animals for protein digestion, energy and mineral absorption, especially in young pigs and poultry that have low capacity to secrete gastric acid (Partanen and Mroz, 1999; Makkink, 2001). Therefore, the B-Value of feed for monogastric animals depends on the age of the animal (Table 4). Hence buffering capacity and the use of B-value to formulate feed for monogastrics, especially young ones has been stressed (Bolducan *et al*., 1988).

High B-value produces high pH that encourages gastric fermentation and upsurge of gram negative pathogenic bacteria, while low B-values wreduces gastric fermentation and increases the proliferation of beneficial bacteria such as lactic acid bacteria (Mroz *et al*., 1997). The most practical way to reduce the B-value of a diet is by the addition of organic acids to the diet (Makkink, 2001). Soltan (2008) used organic acid mixture to reduce both the pH and B – Value of diet for laying hens (Table 5).

Organic Acids in Monogastric Animal Feeding

In poultry feeding, organic acids have not gained as much attention as in pig feeding (Waldroup *et al*., 1995; Langhout, 2000). However, a positive influence on either feed conversion ratio or growth performance has been reported for fumaric acid, propionic acid, sorbic acid and tartaric acid (Izat *et al.*, 1990; Berchieri and Barrow, 1996). Ndelekwute *et al.* (2010) had also reported that addition of acetic, citric and formic acids to broiler diets improved growth and economic returns.

Organic acids exhibit antimicrobial properties to achieve a positive influence on the general performance of chickens, especially broilers. Organic acids reduce unfriendly microorganisms in the gut such as *E. coli* and *salmonella* that could destroy vitamins and amino acids (Dibner, 2004; Ndelekwute *et al*., 2011a)). They prevent the thickening of the gut wall thereby allowing to some extent better digestibility (Ndelekwute *et al*., 2011a) and absorption of nutrients (Dibner, 2004). Organic acids inhibit the action of toxin producing bacteria such as fermentation that produces ammonia and methane in the gut and induce endogenous secretions such as secretions of the pancreas (protease and carbohydrase).

Botsoglou *et al*. (2002) noted that organic acids and in fact feed additives with antibacterial properties perform better in an unhygienic condition emphasizing the use of adequate dietary level while Oviedo (2006) reported that overdose could lead to reduction of feed and water intake, which he attributed to the strong taste of the acids.

Earlier, Patten and Waldroup (1988) found that the addition of 1.5% calcium formate in broiler diets reduced weight gain. Besides, Cave (1978) reported that when high level of propionic acid was given through drinking water, feed and water intakes were reduced and subsequently weight gain was reduced. Later, Cave (1984) maintained that the acid had influence on the satiation regulatory system to reduce feed and water consumption. Ndelekwute *et al.* (2010) noted that feeding of diet containing butyric acid reduced feed intake and consequently the live weight of broiler chickens and attributed the poor feed intake to unpleasant odour of the acid which led to poor acceptability of the diet. However, the same authors noted that feeding of drinking water containing acetic, citric or formic acid led to better live weight as shown in Table 5. The table is indicating that except butyric acid all the organic acids improved final live weight of broiler starter chicks over the control indicating that apart from adding organic acids in feed they could also be added in drinking water.

Feeding trials have been conducted also to ascertain the effect of organic acid mixtures on growth, antibacterial, antifungal and as well as their effect on egg production, egg quality and villus height. Table 6 shows the effect of mixtures of formic acid and salts of lactic, propionic and butyric acids on hen day, egg quality and blood parameters according to Soltan (2008). It could be observed that diet containing organic acid mixture at 780ppm significantly ($P<0.05$) improved both the hen day, serum calcium, egg mass, shell thickness, egg shell quality, serum protein and net income compared to the control diet. The result also indicates that the better hen day was achieved without extra feed intake by the birds fed diet containing 780ppm organic acid mixture. This is an indication of economic advantage as shown by the higher net income.

In feeding trial conducted by Paul *et al*. (2007) combination of ammonium formate, calcium propionate and calcium lactate showed antibacterial and antifungal effect in the feed and gastrointestinal tract (Table 7) especially against *E. coli* and *Salmonella*. The height of the villi was increased over the control. The authors attributed better feed conversion recorded by the organic acid combination to the antimicrobial action and the positive effect on the villi height.
The importance of organic acids in pig production was stressed by Soltan (2008) who observed that feeding of organic acids (Table 8) improved weight gain and feed: gain ratio of weaned pigs over the control. From the same Table 8, the performance of pigs that consumed diets containing blend of organic acids (T4) was comparable to the ones that consumed blend of antibiotics (T2).

CONCLUSION

Considering the antimicrobial action of organic acids and their ability to induce secretion of digestive enzymes and mucus which could lead to enhanced digestibility, absorption and reported better growth, organic acids stand a good chance to replace pharmaceutical antibiotics in monogastric animal diets.

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Table 1: Structural Formula and pKa of some Organic Acids

Acids	Structural Formula	MW	pKa
Acetic acid	CH_3COOH	60.05	4.76
Butyric acid	$CH_3CH_2CH_2COOH$	88.10	4.82
Citric acid	$COOHCH_2C(OH)COOHCH_2COOH$	192.12	3.13
Formic acid	HCOOH	46.02	3.75
Lactic acid	$CH_3CH(OH)COOH$	90.08	3.83
Propionic acid	CH_3CH_2COOH	74.08	4.88
Sorbic acid	CH_3CH:CHCH: CHCOOH	112.12	4.76
Tartaric acid	(OCHCH (OH)CH(OH)COOH	150.09	2.93

Source: Dibner (2004). MW = Molecular weight

Table 2: Organic Acid Content of Some Fruits (mg/100g)

Fruits	MC	pH	Ascorbic acid	Citric acid	Total acid
Pineapple	87.3	3.5	11.7	218	246
Orange	90.3	3.5	55.3	452	497
Grape	92.3	3.2	45.4	1312	1382
Lime	91.20	1.4	29.4	4124	4187

Source: Falade *et al*. (2003). MC = Moisture content.

Table 3: B-value of Some Feed Ingredients

Ingredients	pH	B-value
Maize (yellow)	6.1	3.5
Cassava	5.2	1.3
Wheat middlings	6.7	11.4
Sorghum (Milo)	5.9	5.0
Wheat	6.7	3.7
Rice	6.5	2.8
Soyabean meal	6.6	28.8
Soyabean hulls	6.1	8.5
Soyabeans	6.3	18.0
Sunflower seed hulls	6.1	16.4
Meat meal	6.0	26.0
Meat and bone meal	6.3	32.0
Dicalcium phosphate	7.3	248.0
Limestone	9.7	1750.0

Source: Makkink (2001)

Table 4: Recommended Level of B-value of Feed for Young Monogastrics.

	Feed type	B-value
Pig	Prestarter (0-20 days of age)	0-5
	Weaning (20-30 days of age)	5-7
	Starter (30-50 days of age)	5-10
	Grower (50-70 days of age)	10-20
Poultry	Phase 1 (0-10 days of age)	0-10
	Phase 11 (10-30 days of age)	10-20

Source: Makkink (2001)

Table 5: Effect of Organic Acids in Drinking Water on Performance of Starter Broilers

Parameters	CON	AA	BA	CA	FA	SEM
Initial body weights (g)	115.20	116.75	114.46	116.56	116.29	2.88
Final body weight (g)	730.09^{c}	869.07^{a}	747.22^{c}	807.41^{b}	803.70^{b}	14.11
Daily weight gain (g)	29.28^{b}	35.82^{a}	30.13^{b}	32.90^{ab}	32.73^{ab}	2.00
Daily feed intake (g)	56.04	57.31	57.32	57.71	57.21	3.16
Feed: gain ratio	1.91^{a}	1.06^{b}	1.90^{a}	1.75^{b}	1.75^{b}	0.14
Daily protein intake (g)	12.00	12.27	12.27	12.36	12.25	1.76
Protein efficiency ratio	2.44^{b}	2.92^{a}	2.46^{b}	2.66^{a}	2.67^{a}	0.10
Daily water intake (ml)	130.56^{a}	122.88^{ab}	107.54^{c}	118.23^{bc}	117.51^{bc}	11.00
Water: feed ratio	2.33^{a}	2.14^{b}	1.88^{c}	2.05^{b}	2.05^{b}	0.11

Source: Ndelekwute *et al*. (2011b)

Table 6: Effect of Organic Acid Mixture on Performance of Laying hens and the Feed

		Levels (%)			
Parameters	**T1 (0 ppm)**	**T2 (260 ppm)**	**T3 (520 ppm)**	**T4 (780 ppm)**	**± SD**
Feed pH	6.35^{a}	6.45^{a}	6.41^{ab}	6.31^{b}	0.01
Feed B - Value	20.10	18.20	16.90	16.10	-
Live weight (kg)	1.74^{b}	1.82^{ac}	1.81^{ac}	1.79.^{bc}	0.03
Feed intake (g/hen/day	108.77	108.23	108.99	108.65	0.28
FCR	2.19^{a}	2.03^{b}	2.08^{a}	1.97^{c}	0.03
Hen day (%)	80.64^{b}	80.93^{b}	80.24^{b}	85.29^{a}	0.30
Egg weight (kg)	64.57	66.05	65.02	65.40	1.13
Egg mass	52.44^{c}	53.64^{b}	52.57^{c}	55.94^{a}	0.64
Shell Calcium (%)	18.40	18.78	19.50	18.38	0.43
Shell Phosphorus (%)	0.15	0.14	0.16	0.16	0.01
Thin shell (% TEP)	1.45^{ab}	1.51^{a}	1.34^{b}	0.72^{c}	0.21
Shell thickness (mm)	0.32^{b}	0.32^{b}	0.35^{a}	0.36^{a}	0.01
Broken shell (TEP)	0.33^{a}	0.34^{a}	0.31^{a}	0.25^{b}	0.03
Shell weight (g)	7.92	7.56	8.23	8.22	0.29
Egg index	0.76	0.77	0.77	0.77	0.01
Yolk index	39.56^{b}	44.69^{ac}	42.26^{bc}	45.68^{a}	1.14
Albumen index	5.58	5.19	5.02	5.31	0.01
Serum calcium (%)	19.38^{c}	21.43^{bc}	22.09^{b}	24.45^{a}	0.60
Serum phosphorus (%)	0.15	0.14	0.16	0.16	0.01
Serum protein (%)	3.98^{b}	3.62^{b}	4.32^{a}	4.72^{a}	0.11
Mortality (%)	7.86	17.48	8.44	8.67	-
Net income (US$)	16348	15648	13702	20649	-

TEP = total egg production. Source Soltan (2008)

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Table 7: Effect of Antibiotic and mixture of Organic Acid Salts on Growth, Microbial Load and Villus Height of Broiler Chickens

Parameters	T_1 0.05%	T_2 0.15%	T_3 0.10%	SEM
Growth performance				
Live weight (g)	2035	1989	2090	21.28
Weight gain (g)	1995	1949	2090	21.08
Feed intake (g)	3405^a	3182^b	3380^b	15.43
FGR	1.75^a	1.63^b	1.65^b	0.01
Antibacterial action				
Feed sample (cfu/g feed)				
Coliforms ($x10^2$)	11.5^{ab}	13.5^a	10.5^b	2.89
E. coli ($x10^2$)	-	1.5	-	-
Salmonella	-	-	-	-
Clostridium ($x10^2$)	110	135	135	3.33
Antifungal action				
Aspergilus niger ($x10^2$)	2	-	-	-
A. flavus ($x10^2$)	2	1	-	-
A. fumigatus ($x10^2$)	2	-	-	-
Intestinal digesta (cfu/g)				
E. coli ($x10^5$)	9.5^a	7.5^b	1.5^c	0.75
Salmonella	-	-	-	-
Clostridium ($x10^5$)	2.5^b	4.0^a	3.8^a	0.33
Villus height (µm)				
Duodenum ($x10^{-3}$)	1158^b	1119^b	1456^a	15.50
Jejunum ($x10^{-3}$)	1017^b	1124^a	1028^a	8.50
Ileum ($x10^{-3}$)	547^c	607^b	672^a	6.75

Sources: Paul *et al*. (2007)

T_1 = Virginiamycin, T_2 = Ammonium format + Calcium propionate, T_3 = Ammonium formate + Calcium propionate + Calcium lactate

Table 8: Effect of Antibiotics and Organic Acids on Performance of Weaned Pigs

Parameters	T_1	T_2	T_3	T_4	SEM
Av. Daily gain	323^b	395^a	354^{ab}	371^a	16.23
Av. Daily intake	539	576	543	545	31.33
Feed: gain ratio	1.68^a	1.46^b	1.52^{ab}	1.47^b	0.06

Source: Li *et al*. (2008)

T1 = control, T2 = 200ppm chlortetracycline + 60ppm lincospectin, T3 = 0.5% potassium diformate, T4 = 0.5% commercial blend of organic acids

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