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Acidification and other physiological additives

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SUMMARY – Physiological additives are those that help the normal development of physiological functions of animals or that make up for their deficiencies. Among these, acidifiers, *Yucca schidigera* extracts and fructo-oligosaccharides (FOS) have to be considered. Acidification is crucial in young animals, which cannot secrete enough hydrochloric acid for a correct protein digestion. Numerous studies have shown that inorganic-based acidifiers are the most appropiate to achieve not only a regular digestion, but improvements in health and performances. Yucca extracts are used as dietary supplements for any animal species, primarily for ammonia and odor control, thus improving environmental conditions and, consequently, health and performances. In ruminants, Yucca extracts improve nitrogen utilization through their antibacterial and antiprotozoal function, favoring the activity of beneficial bacteria. Finally, FOS act also benefitting the saprofitic flora in detriment of the pathogenic flora, thus improving health and performances both in young and adult animals.

Key words: Inorganic-based acidifiers, *Yucca schidigera*, fructo-oligosacharids.

RESUME – *"L'acidification et autres additifs physiologiques". Les additifs physiologiques sont ceux qui aident au déroulement normal des fonctions physiologiques des animaux ou à pallier leurs déficiences. Parmi ces derniers, il faut considérer les acidifiants, les extraits de* Yucca schidigera *et les fructo-oligosaccharides (FOS). L'acidification est cruciale chez les jeunes animaux, qui ne peuvent pas sécréter suffisamment d'acide chlorhydrique pour une digestion correcte des protéines. De nombreuses études ont montré que les acidifiants à base inorganique sont les plus indiqués pour obtenir non seulement une digestion régulière, mais une amélioration de la santé et des performances. Les extraits de Yucca sont utilisés comme suppléments diététiques chez toutes les espèces animales, en premier lieu pour le contrôle de l'ammoniac et de l'odeur, ce qui améliore les conditions du milieu et par conséquent la santé et les performances. Chez les ruminants, les extraits de Yucca améliorent l'utilisation de l'azote à travers sa fonction antibactérienne et antiprotozoaire, favorisant l'activité des bactéries bénéfiques. Finalement, les FOS agissent également en favorisant la flore saprophyte au détriment de la flore pathogène, améliorant ainsi la santé et les performances chez les jeunes animaux et chez les adultes.*

Mots-clés : *Acidifiants à base inorganique,* Yucca schidigera*, fructo-oligosaccharides.*

Introduction

The possibilities for maximizing females and, consequently, farm productivity have led the producers to wean animals at an earlier age. Also, the need to more efficiently utilize alternative ingredients in the diets for these young animals instead of milk components, such as soybean meal or fishmeal, to achieve more optimum and economical feed formulations together with the ban of antibiotic growth promoters, has encouraged nutritionists to develop physiological additives to avoid scouring and improve performances. Physiological additives are those that help to the normal development of physiological functions of animals or that make up for their deficiencies. Among this deficiencies we can found the inability of the early weaned animals to secrete sufficient quantities of hydrochloric acid within the stomach and the insufficient secretion and activity of digestive enzymes, or the lack of certain enzymes for young and adult animals to digest rather indigestible substances for the monogastric animals, such as non-starch-polysaccharides. This paper is focussed on some of these physiological additives for animal feeds, such as inorganic-based acidifiers, saponins and glycocomponents from *Yucca schidigera* and fructo-oligosaccharides (FOS).

Acidification and utilization of inorganic-based acidifiers

The term acidification includes the reduction of pH in feeds and in the animal digestive tract, mainly in the stomach. Acidification of young animal diets is not a new concept in the feed industry and its ultimate aims are: (i) to help to maintain the optimal pH in the stomach, allowing a correct activation and function of the proteolytic enzymes, thus permitting total protein digestion in the stomach; and (ii) to stimulate feed consumption.

Young animals have limited ability to produce hydrochloric acid in the stomach. At birth, hydrochloric acid production is negligible, but it increases with advancing age. The greater the production of acid in the stomach, the lower the gastric pH. In the stomach, pH can regulate the movement of viable bacteria and molds from the animal's environment to the small intestine and is involved in the activation of pepsin, a proteolytic enzyme. Pepsin is secreted as an inactive zymogen, pepsinogen, and its conversion to the active pepsin is catalyzed by the action of acid and any existing pepsin in the stomach. Additionally, the optimal pH for pepsin activity is 2.0. At higher pHs, activity is severely reduced. The initial proteolytic activity carried out by pepsin is necessary for the subsequent activity of trypsin in the small intestine. An additional important role for stomach acid is the protection of the lower part of the digestive tract from bacterial invasion (Easter, 1988). The low pH (2.0 or less) commonly found in normal growing and adult animals has been shown to have a pronounced bacteriostatic effect. Thus, viable microorganisms entering the digestive system via the mouth are unable to pass through the stomach and successfully colonize in the small intestine.

In suckling animals, lactose is converted to lactic acid by the *Lactobacillus* bacteria normally resident in the stomach. Moreover, milk is curdled in the stomach by the action of chymosin, which allows a longer stay and thus action of pepsin, even if pH is not as low as the optimal. When vegetable proteins instead of milk proteins are fed to those animals, curdling does not take place and a pH of 2 is not achieved because of the lack of hydrochloric acid. This type of proteins and, to a larger extent mineral mixtures, bind free hydrochloric acid, thus contributing even more to decrease available acid for protein digestion. In this case, undigested feed goes into the small intestine, where pathogenic bacteria can utilize them for their benefit. Also, when pH is above 4, most of these pathogenic bacteria can freely develop.

Adding inorganic-based acidifiers to the feed can reduce its bacterial contamination as well as assisting in the adjustment of the pH towards a more suitable level. Inorganic acids are more effective in reducing the acid-binding capacity of feed at a gastric level and they also show higher persistence in the gut than organic acids (Daza *et al*., 1997). Among the inorganic acids more commonly tested (hydrochloric, phosphoric and sulphuric acids), only phosphoric acid has shown improvements in performances (Giesting, 1986; Daza *et al*., 1997). Nevertheless, different experiments have demonstrated that combinations of organic acids with phosphoric acid, thus giving rise to phosphoric acid-based acidifiers, show better results than combinations of organic acids alone, as phosphoric acid complements them (Schutte and de Jong, 1988; Schoenherr, 1994).

An experiment conducted at the Institute of Animal Nutrition and Physiology (ILOB) in The Netherlands comparing a control diet with the same diet with added simple organic acids, blends of organic acids or DIGESTOCAP, a phosphate-based acidifier, showed that all the products tested improved performances in relation to the control. Nevertheless, DIGESTOCAP was the acidifier that presented a greater weight gain (+4.4%) and feed intake (+3.2%) and one of the lowest feed/gain ratios (–1%) of the trial, even with a lower dose of inclusion in the diet, as can be observed in Table 1 (Schutte and de Jong, 1988). All the diets were composed of a basal diet, without any palatable substances added, and with the correspondent acid blend included according to treatment. Diet with DIGESTOCAP was the one that showed a higher feed intake, thus suggesting a higher preference of the piglets for this one. In addition, homogeneity of piglets was also higher using DIGESTOCAP in relation to the other treatments. This latter aspect was also verified in a trial conducted in Thailand with pigs from 5 to 10 weeks of age (Table 2). More recent research conducted in Germany demonstrated that dietary inclusion of inorganic acids alone at high levels (around 3%) was higher than needed to improve growth performance of weaned pigs. High levels of dietary inclusion have a negative effect on growth performance, likely attributed to alteration of electrolyte balance or negative effects on feed palatability (Schoenherr, 1994).

Following with the research conducted at the ILOB (Schutte and de Jong, 1988), Brufau (1989) evaluated three different doses of a phosphoric-based acidifier, DIGESTOCAP, to determine the more effective dose of that supplement for a piglet diet. This author demonstrated that, although the three evaluated doses (0.1, 0.2 and 0.3%) showed higher performances than the control, doses between 0.1 and 0.2% presented the best results, as shown in Table 3.

Table 1. Effect of adding different acidifiers in pig starter diets from 5 to 9 weeks of age (n = 400)

Treatment	Weight gain (kg)	Feed/gain ratio	Daily feed intake (% of the control)
Control	13.7	1.532	100.0
1.5% Fumaric acid	14.2	1.511	102.1
1.5% Calcium formate	13.9	1.517	100.4
1.5% Calprona P†	14.0	1.509	100.5
1.5% ICD-1††	14.0	1.523	101.6
1.5% ICD-2†††	13.7	1.516	98.9
0.3% DIGESTOCAP††††	14.3	1.516	103.2

†Calprona P: formic acid, acetic acid and propionic acid.
††ICD-1: fumaric acid, calcium formate and monoammonium formate.
†††ICD-2: propionic acid, phosphoric acid, fumaric acid, calcium formate and carrier.
††††DIGESTOCAP: orto phosphoric acid, citric acid and fumaric acid.

Table 2. Effect of supplementation with DIGESTOCAP to pig feed from 5 to 10 weeks of age on piglet performances (ITPSA, 1996)

Treatment	Weight gain (kg)	Feed intake (kg)	Feed/gain ratio	Coefficient of variation (%)	
				Initial body weight	Final body weight
Control	14.45	22.65	1.567	13.82	17.86
DIGESTOCAP	15.90	24.87	1.564	13.75	14.24

Table 3. Effect of different doses of DIGESTOCAP in the feed on piglet performances during a period of 47 days after weaning (n = 120)

Treatment	Weight gain (kg)	Feed/gain ratio	Advantage of DIGESTOCAP (%)	
			Weight gain	Feed/gain ratio
Control	16.8	1.73	–	–
0.1% DIGESTOCAP	19.3	1.66	14.9	4.2
0.2% DIGESTOCAP	18.1	1.66	7.7	4.2
0.3% DIGESTOCAP	17.3	1.68	3.0	3.0

Additional research conducted in Germany with phosphoric acid-based acidifiers in piglets (Schoenherr, 1994) also showed similar results respect to control diets for weight gain (+10.8%), feed intake (+6.3%) and feed/gain ratio (–4.8%). This author pointed out that the majority of the growth response occurs during the first two weeks postweaning, but that there is also additional value to acidifying diets in the latter portion of the nursery period.

Phosphoric acid-based acidifiers have also shown its efficacy in other animal species. Calafat and Puchal (1993) observed in 4 week-aged rabbits significant improvements in performances and also in mortality, as can be observed in Table 4.

Table 4. Effect of DIGESTOCAP R supplementation in rabbit diets during fattening

Treatment	Daily weight gain (g)	Daily feed intake (g)	Feed/gain ratio	Mortality (%)
Control	41	145	3.55	16.28
DIGESTOCAP R	42	147	3.46	11.63

Addition of acidifiers, phosphoric-based or organic ones, is also necessary in acidified milk replacers for ruminants. Many authors have shown that this type of milk replacers causes less alimentary tract disorders than ordinary milk replacers, particularly when fed *ad libitum* (Hand *et al*., 1985; Fallon and Harte, 1986). When evaluating acidified milk replacers in calves, these authors also reported an increase in live-weight gain and feed conversion efficiency. The acid in the milk is expected to reduce the pH in the digestive tract, bearing the following advantages: (i) to improve protein clotting; (ii) to increase renine secretion which, in turn, favours clot formation and improves its digestibility; (iii) to increase secretion and activation of other enzymes, as pepsin; (iv) to inactivate trypsin inhibitors; and (v) to preserve feed from bacterial contamination.

In view of the results, it has to be considered that phosphoric acid-based acidifiers, when used at proper levels of dietary inclusion, offer the advantages of: (i) lowering the cost of acidifying starter diets or milk replacers; (ii) they use less space in formulation than organic acids; (iii) yield a similar growth performance enhancement; (iv) phosphoric acid-based acidifiers provide totally available phosphorus to the animals; and (v) as it is totally available, phosphoric acid-based acidifiers act as a non-contaminant source of phosphorus for the animal.

Yucca schidigera **as a digestion improver**

Another physiological supplement that has to be considered is *Yucca schidigera* extract. *Yucca schidigera* is a native plant of the Baja California desert in Mexico and the Mojave Desert in California, Arizona and Nevada, in the United States. Its active ingredients are, mainly, steroidal saponins and glycocomponents. Steroidal saponins have highly tensoactive properties. They play an important role in animal nutrition and, due to their strong surfactant power, the cell membranes of the intestinal wall become able for a better absorption of nutrients (Johnston *et al*., 1981; Oleszek *et al*., 1994), and also increases the intestinal flora activity, improving the digestive process. Glycocomponents are molecular structures highly thermostable that have the ability to capture ammonia molecules in the digestive tract and in the metabolic processes, neutralizing its noxious effects and converting it into another type of non-toxic nitrogenated compounds, thus improving the intestinal conditions. As a consequence, the flora increases its degrading activity that results in a more complete digestion. At the same time, these compounds reduce the amount of ammonia released to the environment by around 34%, as well as hydrogen sulfide (50%) and other toxic gasses produced in the degradation process of the excretions, improving the environmental conditions of the confinement areas and bringing, as a consequence, better production conditions and better productive parameters. In this sense, a recent study carried out by ITPSA with 4500 male pigs during 90 days, in Jalisco, in Central Mexico, by adding 100 to 120 g/Mt of feed of CAPSOGENIN BIOPOWDER, a Yucca extract based product, showed a significant reduction for the levels of environmental and metabolic ammonia, diminishing the appearance of respiratory illnesses and improving nutrient absorption, feed conversion and daily weight gain (Table 5).

Other studies carried out by ITPSA and also by other authors (Hale *et al*., 1961; Dziuk *et al*., 1981; Johnston *et al*., 1981; Goodall *et al*., 1982; Al-Bar *et al*., 1993) have also shown improvements in growth and feed efficiency when adding between 31 and 155 p.p.m. extracts of *Yucca schidigera* in diets for broilers, turkeys, rabbits, lambs or cattle. Also in layer hens an increase in egg production was observed (Rowland *et al*., 1976). Reduction in the liberation of ammonia to the environment and improved faecal aroma have also been reported in horses (Glade, 1992), dogs and cats (Lowe *et al*., 1997).

Table 5. Effects of adding 100 to 120 g/Mt of feed of CAPSOGENIN BIOPOWDER (CBP) on productive parameters of pigs

Treatment	Mortality (%)	Initial weight (kg)	Final weight (kg)	Weight gain (kg)	Daily weight gain (g)	Feed/gain ratio	Carcass yield (kg)
With CBP	0.9	40.30	107.41	67.11	0.799	2.782	81.95
Without CBP	1.8	38.60	103.00	64.41	0.767	2.846	80.21
Advantage of CPB	0.9	–	4.28	4.19	4.172	2.249	2.169

Thus, Yucca is currently used as dietary supplement for livestock and companion animals, primarily for ammonia and odor control, but also to improve performances. Nevertheless, *Yucca saponin* also have strong antiprotozoal activity and may serve as an effective defaunating agent for ruminants (Wallace *et al*., 1994). The mechanism for this action appears to be by forming irreversible complexes with cholesterol in the cell membranes of all microorganisms except bacteria, causing its breakdown and cell lysis (Cheeke, 1999). The antiprotozoal activity requires the intact saponin structure. However, it can be hydrolized by rumen bacteria, removing the carbohydrate side-chains, and rendering them inactive against protozoa. This may result from adaptation of bacterial metabolism to utilize saponins in the diet (Hristov *et al*., 1999). Thus, one approach for retaining anti-protozoal activity would be to feed saponins intermittently, to suppress protozoa but without continuous presence of saponins to induce bacterial adaptation (Cheeke, 1999). As a result of suppression of those rumen protozoa, dietary saponins increase the outflow of bacterial protein from the rumen to the intestine, thus benefiting the ruminant by increasing the amount of amino acids available for absorption (Wallace *et al*., 1994).

In ruminants, Yucca extract can also stimulate growth of certain bacteria, as *Prevotella ruminicola*, *Selenomonas ruminantium* (Wallace *et al*., 1994) and Bifido bacteria (Grandhi, 1998), and suppress others, as *Streptococcus bovis* and *Butyrivibrio fibrisolvens* (Wallace *et al*., 1994). The antibacterial properties are most pronounced against gram-positive bacteria, with an action similar to the ionophores. Nevertheless, the mode of action of antibacterial effects of saponins seems to involve membranolytic properties, rather than simply altering the surface tension of the extracellular medium, therefore being influenced by microbial population density (Killeen *et al*., 1998).

In conclusion, as digestibility of dietary fiber is not adversely affected in ruminants when supplementing the diet with Yucca extract, reducing protozoal populations in cattle improves nitrogen utilization in the rumen and increases microbial protein flow to the intestine (Hristov *et al*., 1999), thereby enhancing overall growth performance, acting as a growth promoter (Goodall *et al*., 1982).

Fructo-oligosaccharides: Intestinal flora adjuster

FOS are β-linked fructose units to the fructose moiety of sucrose (GF_1) in a variable quantity: GF_2, GF_3, GF_4, etc. They can be found in most cereals, including barley and wheat, and also in other plants, as onions or asparagus (Hidaka *et al*., 1983), accounting for between 0.2 and 2% of their dry matter content. The aim of FOS, mainly short chain FOS (GF_2, GF_3 and GF_4), is to beneficially affect the animals by selectively stimulating growth and activity of one or a limited number of beneficial endogenous bacteria in the colon, avoiding enteric processes and improving health and performances, thus acting as a prebiotic (Gibson and Roberfroid, 1995).

FOS are not hydrolyzed by digestive enzymes of the gastrointestinal tract (Oku *et al*., 1984). Nevertheless, they can be selectively metabolized by different bacterial species (Tokunaga *et al*., 1989), as *Bifidobacterium*, *Lactobacillus* or *Eubacterium*, which in turn, are activated by FOS, so suggesting that a chronic intake of FOS improves the environment of the gastrointestinal tract by increasing beneficial microorganisms and decreasing putrefactive ones, such as others, *E. coli* and *Clostridium perfringens* (Hidaka *et al*., 1983).

FOS have been shown to alter volatile fatty acids in the lower gastrointestinal tract and to reduce caecal ammonia odorous compounds from feces as a result of flora modification in pigs (Tokunaga *et al*., 1989; Sutton *et al*., 1999). Also, lactic acid concentration increases five-fold in the colon, as a consequence of FOS supplement in diets for pigs (Bolduan, 1999). All these acids in the colon contribute towards a pH diminution, thus creating a non-favourable environment to pathogen microorganisms (Morisse *et al.*, 1985). Additionally, volatile fatty acids are absorbed, contributing to cover the energetic needs of the animals.

Different works have shown improvements in health and performances in pigs (Houdijk *et al*., 1999; Varley, 1999), poultry (Barrow, 1992), rabbits (Morisse *et al*., 1992; Lebas, 1993) and dogs (Willard *et al*., 1994). Recent experiments (Bruneau, pers. comm.) on short chain FOS in pigs during the first days after weaning (from 27 to 39 days of age) and also during fattening (from 35 to 68 days of age) have shown improvements in growth and feed conversion rates compared to control diets and also to avoparcine supplemented diets, as observed in Table 6.

Table 6. Effects of supplementing short chain FOS (PROFEED) in diets for piglets (0.34% PROFEED from 27 to 39 days of age; Netherlands, 1994) and fattening pigs (0.15% PROFEED from 35 to 68 days of age; France, 1990)

Item	Control	Control + 40 p.p.m. avoparcine	Control + PROFEED	PROFEED advantage to control
Piglets				
Number	40	40	40	
Daily weight gain (g/d)	227	231	248	+9.3%
Daily feed intake (g/d)	278	279	285	+2.5%
Feed/gain ratio	1.22	1.21	1.15	–6.1%
Fattening pigs				
Number	214	–	216	
Daily weight gain (g/d)	364	–	383	+5.2%
Daily feed intake (g/d)	781	–	745	–4.8%
Feed/gain ratio	2.15	–	1.94	–10.8%
Mortality (%)	2.8	–	2.3	–21.7%

Also, a trial carried out by Bruneau (1991, pers. comm.) in adult female rabbits showed more weaned rabbits per female, a lower mortality and a higher average weight at weaning, thus increasing farm yield, as shown in Table 7. Short chain FOS significantly increase volatile fatty acids and decrease caecal ammonium nitrogen in rabbits, through modifications in the digestive microflora.

Table 7. Effects of supplementing adult female rabbit diets with PROFEED, a short chain FOS, on female productivity, rabbit mortality and wean weight (France, 1991)

Item	Control	Control + PROFEED	Advantage of PROFEED
Number of births	148	92	
Number of rabbits/birth	10.25	9.87	–3.85%
Number of live rabbits/birth	9.25	9.24	–0.10%
Weaned rabbits/birth	6.84	7.64	+11.70%
Number of fattening rabbits/birth	6.20	7.27	+17.26%
Birth mortality (%)	9.75	6.4	–34.36%

Mortality before weaning (%)	26.05	17.32	–33.51%
Mortality during fattening (%)	9.36	4.84	–48.29%
Average weight at weaning (g)	620.0	663.1	+6.95%

In conclusion, short chain FOS offer the following advantages: (i) to allow microbial manipulation, favouring the growth of beneficial microorganisms to the detriment of pathogen and putrefactive bacteria; (ii) to decrease odorous compounds in feces; (iii) to improve performances and health status of animals, preventing digestive disorders; and (iv) to increase farm profits.

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