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Measurements of the acid-binding capacity of ingredients used in pig diets

Peadar G. Lawlor[1], P. Brendan Lynch[1], Patrick J. Caffrey[2], James J. O'Reilly[1] and **M. Karen O'Connell[1]**

[1] Pig Production Department, Teagasc, Moorepark Research Centre, Fermoy, Co. Cork, Ireland
[2] Department of Animal Science and Production, Faculty of Agriculture, University College, Dublin, Ireland.

Some feed ingredients bind more acid in the stomach than others and for this reason may be best omitted from pig starter foods if gastric acidity is to be promoted. The objective of this study was to measure the acid-binding capacity (ABC) of ingredients commonly used in pig starter foods. Ingredients were categorised as follows: (i) milk products (n = 6), (ii) cereals (n = 10), (iii) root and pulp products (n = 5), (iv) vegetable proteins (n = 11), (v) meat and fish meal (n = 2), (vi) medication (n = 3), (vii) amino acids (n = 4), (viii) minerals (n = 16), (ix) acid salts (n = 4), (x) acids (n = 10). A 0.5g sample of food was suspended in 50ml distilled de-ionised water with continuous stirring. This suspension was titrated with 0.1mol/L HCl or 0.1 mol/L NaOH so that approximately 10 additions of titrant was required to reach pH 3.0. The pH readings after each addition were recorded following equilibration for three minutes. ABC was calculated as the amount of acid in milliequivalents (meq) required to lower the pH of 1kg food to (a) pH 4.0 (ABC-4) and (b) pH 3.0 (ABC-3). Categories of food had significantly different ($P<0.01$) ABC values. Mean ABC-4 and ABC-3 values of the ten categories were: (i) 623 (s.d. 367.0) and 936 (s.d. 460.2), (ii) 142 (s.d. 79.2) and 324 (s.d. 146.4), (iii) 368 (s.d. 65.3) and 804 (s.d. 126.7), (iv) 381 (s.d. 186.1) and 746 (s.d. 227.0), (v) 749 (s.d. 211.6) and 1508 (s.d. 360.8), (vi) 120 (s.d. 95.6) and 261 (s.d. 163.2), (vii) 177 (s.d. 60.7) and 1078 (s.d. 359.0), (viii) 5064 (s.d. 5525.1) and 7051 (s.d. 5911.6), (ix) 5057 (s.d. 1336.6) and 8945 (s.d. 2654.1) and (x) -5883 (s.d. 4220.5) and -2591 (s.d. 2245.4) meq HCl per kg, respectively. Within category, ABC-3 and ABC-4 values were highly correlated: R^2 values of 0.80 and greater for food categories i, iv, v, vi, vii and viii. The correlation between predicted and observed ABC values of 34 mixed diets was 0.83 for ABC-4 and 0.71 for ABC-3. It was concluded that complete diets with low ABC values may be formulated through careful selection of ingredients. The final pH to which ABC is measured should matter little as ABC-3 and ABC-4 are highly correlated.

Key words:
Pig,
Diet,
Ingredients,
Acid-binding capacity.

Introduction

In the pig, protein digestion begins in the stomach with the action of pepsins, secreted as the enzyme precursors – pepsinogens – by stomach mucosa. Conversion of pepsinogen to pepsin occurs rapidly at pH 2.0 but only slowly at pH 5.0 to 6.0. In turn, pepsins work best in an acidic environment, pH 2.0 to 3.5, and activity declines rapidly above this pH. Carbohydrate hydrolysis in the stomach occurs by the action of salivary amylase, which, in contrast to pepsin, is inactivated once pH falls to 3.5 (Kidder and Manners, 1978; Longland, 1991; Yen 2001).

Corresponding author:
P.G. Lawlor
Pig Production Department,
Teagasc, Moorepark Research Centre,
Fermoy, Co. Cork, Ireland
Tel: + 353 25 42217
Fax: + 353 25 42340
E-mail: plawlor@moorepark.teagasc.ie

In the suckling pig, acid secretion is low and the principal source of acidity is bacterial fermentation of lactose from sows milk to lactic acid (Cranwell *et al*., 1968, 1976; Kidder and Manners, 1978). A high level of lactate in the stomach tends to inhibit HCl secretion (Cranwell *et al*., 1976; Yen, 2001). Ingestion of solid feed reduces the level of lactic acid in the stomach (Yen, 2001) and stimulates HCl production (Cranwell *et al*., 1976; Cranwell, 1985) but, in practice, creep feed consumption is low and variable at least up to four weeks of age (Lawlor *et al*., 2002).

At weaning, a combination of low acid secretion, lack of lactose substrate, and consumption of large meals at infrequent intervals can result in elevated pH, often to over 5.0 and it may remain high for several days (Kidder and Manners, 1978). The high acid-binding/buffering capacity of the feed (its ability to neutralise feed acid) helps to further raise the stomach pH (Prohaszka and Baron, 1980; Jasaitis *et al*., 1987; Bolduan *et al*., 1988). Inclusion of whey or lactose in the starter diet ensures continuation of bacterial fermentation and some, though reduced, lactic acid production (Kidder and Manners, 1978; Easter, 1988). Development of HCl secretory capacity occurs more rapidly in the weaned pig than in the suckling pig (Cranwell and Moughan, 1989).

Lowering the acid-binding capacity of diets for newly-weaned pigs can help ease the transition from milk to solid food at weaning.

Raised stomach pH after weaning results in reduced digestion of feed which will then be fermented in the hind gut and may provoke diarrhoea. A high gastric pH will also allow pathogens to survive and allow them greater opportunity to colonise the digestive tract (Bolduan *et al*., 1988; Yen, 2001).

The concept of manipulating stomach acidity by adding acid to feeds or using feeds of low acid-binding or buffering capacity (Prohaszka and Baron, 1980; Jasaitis *et al*., 1987; Bolduan *et al*., 1988; Lawlor *et al*., 2005a; Lawlor *et al*., 2005b) has been around for a long time and addition of organic acids to piglet starter feeds is a common practice. However, there is little information on the acid-binding capacity (ABC) of ingredients that are used in formulation of complete feeds. The limited published sets of data have been compiled using methods with different titration-end points (e.g., pH = 3.0 or pH = 4.0) so that values are not comparable (Prohaszka and Baron, 1980; Jasaitis *et al*., 1987; Bolduan *et al*., 1988; Giger-Reverdin *et al*., 2002).

The objective of this study was to find the ABC and buffering capacity values of individual feed ingredients and ingredient categories and to find if a correlation exists between ABC-3 and ABC-4 values. A further objective was to investigate the possibility of formulating complete diets of low ABC for weaned pigs by using the ABC values of each ingredient in the formulation matrix.

Materials and methods

Procedures

Ingredients commonly used in pig rations were obtained over a number of years from various commercial sources in Ireland. All ingredients (as received) were ground through a 2mm screen using a laboratory hammer mill (Christy and Norris, Scunthorpe, UK), and were stored in air-tight jars at room temperature until analysis. Measurements were completed within one month of receiving each sample. Ingredients were grouped under the following headings for ease of analysis: (i) milk products, (ii) cereals, (iii) root and pulp products, (iv) vegetable proteins, (v) meat and fish meal, (vi) medication, (vii) amino acids, (viii) minerals, (ix) acid salts, and (x) acids. A modification of the procedure of Jasaitis *et al*. (1987) was used to determine pH and acid-binding capacity (ABC). The latter procedure used only pH = 4.0 as the titration endpoint whereas the present study used pH = 3.0 as well as pH = 4.0 as titration endpoints in an effort to provide measures of greater relevance to pig nutrition. All pH measurements were made using a laboratory pH meter (PHM 220, Radiometer, Copenhagen) which was calibrated using certified pH = 4.0 and pH = 7.0 buffer solutions (Radiometer, Copenhagen). A 0.5g sample of ingredient/feed was suspended in 50ml of distilled and de-ionised water and continuously stirred with a magnetic stirrer. Titrations were performed by addition of acid (0.1N HCl) in variable increments (0.1 to 10ml depending on the ingredient type and the stage of titration). Acid was added so that it would take approximately 10 separate additions of acid to reach pH 3.0. Initial pH and all further readings taken during the titration were recorded after equilibration for three minutes. ABC was calculated as the amount of acid in milliequivalents (meq) required to lower the pH of 1kg of sample to (a) pH 4.0 (ABC-4) and (b) pH 3.0 (ABC-3). The buffering capacity (BUF) was calculated by dividing the ABC by the total change in pH units [from initial pH to the final pH of (a) 4.0 (BUF-4) and (b) 3.0 (BUF-3)]. BUF expresses the amount of acid required to produce a unit change in the pH of a feed ingredient / feed sample.

Feeds/ingredients with a pH less than 3 or 4 were titrated as above but against 0.1 N NaOH until pH 4.0 and/or pH 3.0 was reached. ABC and BUF values in these cases were given negative values.

Statistical analysis

The means and standard deviation for each ingredient were calculated for pH, ABC-4, ABC-3, BUF-4 and BUF-3. Regression equations (Proc Reg of Sas Inc., Cary, North Carolina) were established relating ABC-3 to ABC-4 for the ingredients within each category. This procedure was also used to establish the relationship between the predicted and observed ABC-4 and ABC-3 values for 34 mixed pig diets. Predicted values were obtained by including the ABC-4 and ABC-3 values of each individual ingredient in the formulation matrix for the mixed diet.

Results

The mean ABC and BUF values for each ingredient are shown in **Table 1**. The mean ABC of each category and the correlation between ABC-3 and ABC-4 values for each category are shown in **Table 2**. The correlation between predicted and observed ABC values for 34 post-weaning diets is presented in **Table 3**.

Initial pH, ABC-4 and ABC-3 varied greatly between individual ingredients. Categories of ingredients were statistically different ($P<0.01$) with regard to ABC and BUF values but great variation was also found within ingredient categories for initial pH, ABC and BUF.

Acid salts and minerals were the categories that had the highest ABC and BUF values. Great variation occurred between the different mineral types. Zinc oxide, limestone flour and sodium bicarbonate had the highest ABC values. Of the phosphorus sources, defluorinated phosphate had the highest ABC values, dicalcium phosphate and mono dicalcium phosphate had intermediate values, while monammonium phosphate had the lowest values. Meat and fish meal, milk products, amino acids, root and pulp products and vegetable proteins were the categories of organic ingredients with the highest ABC and BUF values. Cereals had the lowest values of the organic ingredient

TABLE 1: pH, acid-binding capacity (ABC) and buffering capacity (BUF) of some commonly used feed ingredients (mean ±s.d.)

Ingredient	N[1]	pH[2]	ABC-4[3]	ABC-3[4]	BUF-4[5]	BUF-3[6]
Milk						
Acid casein	1	3.9	0	200	0	222
Sows milk	2	8.1±0.04	481±1.0	650±70.7	118±0.8	128±14.8
Whey powder	9	6.6±0.31	434±99.9	714±149.3	168±36.5	199±39.9
Milk replacer	4	6.7±0.22	579±54.6	892±97.8	214±38.1	240±40.6
Skim milk	3	7.1±0.20	756±59.6	1105±108.7	242±29.4	268±35.4
Rennet casein	3	8.1±0.06	1423±35.5	1929±76.9	348±4.0	379±11.1
Cereals						
Oat flakes	1	6.7	72	180	27	49
Wheat	12	6.9±0.12	108±14.9	194±15.8	37±5.0	50±3.7
Pin head oats	1	5.5	81	239	56	97
Barley screenings	1	6.7	104	240	39	65
Maize starch	6	7.0±0.78	91±45.6	202±58.5	29±11.4	51±13.5
Maize	8	6.7±0.24	111±35.8	254±53.1	41±10.6	68±11.1
Barley	14	6.6±0.18	113±14.3	266±43.1	43±3.6	73±10.5
Flaked maize	1	7.6	240	424	67	92
Corn distillers	8	4.4±0.17	96±38.6	438±42.9	262±75.4	317±56.3
Pollard	12	6.9±0.29	292±20.6	572±24.0	100±12.1	146±14.7
Root and pulp products						
Sugar	2	5.8±0.06	23±8.4	98±11.8	13±5.2	36±3.5
Cassava	1	5.5	167	393	110	156
Beet pulp	1	6.0	191	480	98	163
Molasses	10	6.1±0.08	399±37.6	790±45.5	190±19.1	255±16.9
Citrus pulp	13	6.8±0.08	373±25.4	873±49.9	135±8.1	232±12.2
Vegetable protein						
Milo distillers	1	4.1	14	276	174	256
Beans	1	6.8	275	473	98	125
Palm kernal	9	5.9±0.10	250±38.2	485±51.5	132±23.2	167±20.2
Peas	10	6.8±0.11	278±24.0	515±43.1	98±9.8	134±12.7
Lupins	1	6.2	337	645	156	204
Maize gluten	15	4.4±0.07	114±19.7	571±79.4	334±73.1	424±71.4
Full fat soya	10	6.9±0.28	480±43.5	823±62.2	166±13.9	212±16.8
Sunflower meal	11	6.7±0.19	482±52.7	852±91.4	180±14.7	231±16.4
Sycomil	1	7.5	622	959	180	216
Rapeseed meal	12	6.3±0.11	498±49.3	945±65.2	215±20.5	284±21.2
Soybean meal	12	7.1±0.06	642±51.1	1068±74.0	210±18.0	263±20.2
Meat and fishmeal						
Meat and bone meal	1	6.6	595	920	214	243
Fishmeal	10	6.7±0.37	738±219.3	1457±334.5	285±96.8	404±105.9
Fat						
Fat	1	4.9	16	137	17	72
Fat blend	1	6.6	363	609	138	168
Medication						
Spiratet	1	5.6	114	340	73	133
Choline chloride	12	6.7±0.52	101±68.6	226±136.0	37±23.5	61±35.8
Tylamix	1	7.0	370	610	123	152
Microbial protein						
Yeast	1	3.4	150	130	-250	325
Amino acids						
Lysine	11	6.5±0.38	123±23.3	695±124.3	50±6.0	200±22.5
Tryptophan	8	7.0±0.23	179±17.1	1024±90.8	60±4.6	258±25.4
Methionine	9	6.5±0.34	192±75.9	1219±267.0	77±23.0	349±52.5
Threonine	11	6.5±0.22	218±57.6	1386±354.2	86±17.2	391±83.4
Minerals						
Ferrous sulphate	3	3.2±0.09	-655±18.1	93±53.2	-821±77.3	456±96.2
Salt	6	7.5±0.18	83±21.5	162±37.5	24±6.8	36±9.1
Copper sulphate	3	5.1±0.06	92±3.3	269±9.2	80±7.1	125±0.6
Cobalt sulphate	3	7.4±0.04	329±6.5	516±9.7	97±3.0	117±1.5
Monammonium phosphate	3	4.2±0.05	46±10.5	815±40.1	247±13.2	687±33.8
Ferrous oxide	3	8.7±0.16	549±78.5	986±78.6	117±15.8	173±12.5
Mould curb	1	5.3	2517	3460	2014	1538
Finisher minerals and vitamins	3	5.2±0.04	3357±305.5	5123±303.9	2772±194.7	2317±104.8
Weaner minerals and vitamins	3	5.2±0.03	4292±1008.9	6302±1054.0	3472±765.1	2819±448.8
Dicalcium phosphate	5	7.6±0.19	3098±1028.5	5666±1852.4	857±293.7	1234±431.2
Sow minerals and vitamins	3	5.3±0.05	5413±216.4	7503±132.3	4182±300.5	3268±117.1
Potassium citrate	3	8.6±0.07	5703±1.6	7851±13.6	1251±19.0	1412±19.1
Mono dicalcium phosphate	9	4.4±0.26	291±159.5	5494±2574.3	1302±980.8	4400±2564.3
Sodium citrate	3	8.4±0.19	6334±13.6	8745±20.5	1449±66.9	1628±58.6
Defluorinated phosphate	3	9.9±0.09	6412±1032.9	10436±337.5	1085±161.0	1511±28.9
Calcium formate	3	7.4±0.15	3983±97.9	12069±409.7	1182±29.6	2760±18.3
Manganese oxide	3	8.8±0.07	6678±1045.7	10887±2264.6	1400±210.9	1887±381.9

Sodium bicarbonate	3	8.7±0.44	12566±554.1	12870±399.1	2706±147.4	2280±110.3
Limestone flour	13	8.9±0.46	12932±21883	15044±2125.4	2661±479.8	2565±380.6
Zinc oxide	3	8.3±0.19	16321±11701	17908±1100.9	3768±193.0	3363±238.0
Acid						
Orthophosphoric acid	3	1.6±0.02	-8858±168.2	-7957±204.5	-3665±54.5	-5616±97.4
Fumaric acid	3	2.3±0.06	-10862±469.6	-4093±669.7	-6314±54.6	-5659±478.7
Formic acid	3	2.3±0.03	-13550±765.0	-3473±110.3	-7824±572.9	-4745±344.7
Citric acid	5	2.2±0.03	-5605±202.2	-2349±164.3	-3156±89.9	-3024±97.5
Ascorbic acid	3	2.8±0.03	-217±28.6	-2249±77.0	-177±19.4	-10159±1048.2
Malic acid	3	2.2±0.15	-7214±694.6	-2550±769.0	-4084±575.8	-3242±333.0
Lactic acid	3	2.4±0.02	-5079±53.9	-1498±23.7	-3129±63.0	-2405±111.3
Acetic acid	3	2.9±0.02	-2283±104.1	-141±24.9	-2011±133.1	-1031±33.6
Propionic acid	3	3.0±0.01	-1358±276.5	-5±8.2	-1348±259.6	-238±412.4
Sorbic acid	1	3.5	-220	120	-400	267

[1]Number of samples. [2]Initial pH of sample. [3]Acid binding capacity to pH 4.0. [4]Acid binding capacity to pH 3.0. [5]Buffering capacity to pH 4.0. [6]Buffering capacity to pH 3.0

categories. Of the ingredients, both inorganic and organic, the acids category had the lowest ABC and BUF values. Most ABC values for the individual acids were negative with orthophosphoric, fumaric, formic, malic and citric acids having the most negative values.

The mean ABC-3 and ABC-4 values for ingredients within categories are well correlated. R^2 values of 0.90 or greater were found for milk products and medication. R^2 values of between 0.85 and 0.90 were found for amino acids and minerals. Both vegetable proteins and meat and fishmeal had R^2 values of between 0.80 and 0.85.

The ABC values for mixed pig starter diets were predicted from the mean ABC value (**Table 1**) of each ingredient in their formulation and their composition in the diet. The correlation between predicted and observed ABC values was relatively good. For ABC-4, R^2 was 0.83 and for ABC-3 the R^2 was 0.71.

Discussion

Some ingredients bind more acid in the stomach than others and for this reason their use in pig starter diets might result in a high gastric pH. A high gastric pH is detrimental to the pig because it allows the proliferation of deleterious micro-organisms (Bolduan *et al.*, 1988) and inhibits protein digestion (Kidder and Manners, 1978; Longland, 1991; Yen, 2001).

In the present study, a range of ingredients that are commonly used in pig diets was examined. It was thought that ingredients of low ABC would be identified which could then be used to formulate a starter diet in such a way that gastric acidity would be promoted. Jasaitis *et al.* (1987) found that mineral additives had higher ABC-4 and BUF-4 values than organic ingredients. In the present experiment, minerals as an ingredient category had the second highest ABC and BUF values of all categories examined. Acid salts were found to have the highest values. Jasaitis *et al.* (1987) found that carbonates and dibasic or tribasic mineral additives had the highest ABC and BUF values. With the exception of the trace minerals zinc oxide and manganese oxide, the present experiment agrees with this finding. Limestone flour and

Table 2: Models for predicting acid-binding capacity to pH 3.0 (ABC-3) from acid-binding capacity to pH 4.0 (ABC-4) for different feed types

Feed type	**N[1]**	**ABC-4**	**ABC-3**	**Y[2]**	**A[3]**	**B[4]**	**(R^2)[5]**	**(Adj. R^2)[6]**	**RSD[7]**
Milk	22	623±367.0	936±460.2	ABC-4	-118.45***	0.79***	0.99	0.99	39.55
Cereals	64	142±79.2	324±146.4	ABC-4	-2.34	0.45***	0.68	0.67	45.41
Root and pulp products	27	368±65.3	804.7±126.7	ABC-4	14.50	0.44***	0.73	0.72	34.75
Vegetable proteins	84	380.7±186.1	746±227.0	ABC-4	-177.57***	0.75***	0.83	0.83	76.49
Meat and fishmeal	11	749±211.6	1508±360.8	ABC-4	-56.66	0.53***	0.83	0.81	91.75
Medication	14	120±95.6	261±163.2	ABC-4	-26.55+	0.56***	0.92	0.91	27.52
Amino acids	39	177±60.7	1078±359.0	ABC-4	7.40	0.16***	0.87	0.86	22.51
Minerals	73	5064±5525.1	7051±5911.6	ABC-4	-1157.30***	0.88***	0.89	0.89	1833.53
Acid salt	10	5057±1336.6	8945±2654	ABC-4	4909.16*	0.02	0.01	-0.12	1416.90
Acid	30	-5883±4220.5	-2591±2245.4	ABC-4	-2771.41**	1.20***	0.41	0.39	3304.56

[1]Number of samples. [2]Dependent variable. [3]Regression constant. [4]Regression coefficient for regression on ABC-3. [5]Coefficient of determination. [6]Adjusted R^2. [7]Residual standard deviation.

Table 3: Models for predicting observed acid-binding capacity to pH 4.0 (ABC-4) and observed acid-binding capacity to pH 3.0 (ABC-3) from their respective predicted ABC values

Measure	**N[1]**	**Observed value**	**Predicted value**	**Y[2]**	**A[3]**	**B[4]**	**(R^2)[5]**	**(Adj. R^2)[6]**	**RSD[7]**
ABC-4	34	259±93.3	294±124.8	Observed ABC-4	59.50**	0.68***	0.83	0.82	39.11
ABC-3	34	608±88.8	640±77.6	Observed ABC-3	-9.32	0.97***	0.71	0.70	48.28

[1]Number of samples. [2]Dependent variable. [3]Regression constant. [4]Regression coefficient for regression on predicted ABC-4 or ABC-3 value. [5]Coefficient of determination. [6]Adjusted R^2. [7]Residual standard deviation.

sodium bicarbonate had the highest ABC values with defluorinated phosphate, dicalcium phosphate and mono dicalcium phosphate being the minerals with the next highest values. Bolduan (1988) found that increasing the mineral supplementation of a diet from 0 to 4% tripled the ABC-4 value. For this reason, Bolduan *et al.* (1988) and Bolduan (1988) suggested limiting the mineral content of a starter diet for a short period postweaning. It was hypothesised that this practice would benefit the pigs in health terms. However, growth may be retarded to some extent by this practice as the mineral requirement for bone formation will not be supplied (Bolduan, 1988) especially if the period of restricted feeding of minerals is prolonged.

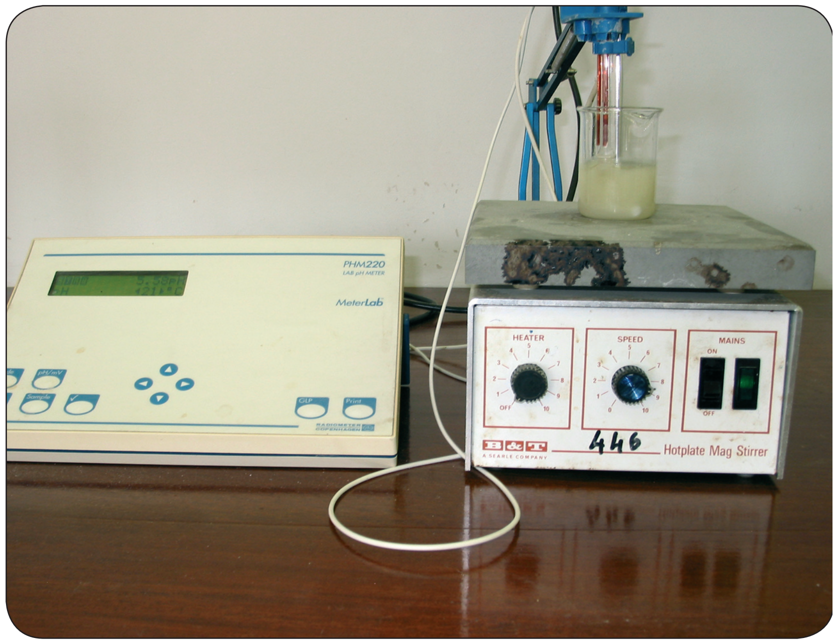
With regard to organic ingredients, their ABC values are positively correlated with their ash and protein contents (Jasaitis *et al.*, 1987; Bolduan *et al.*, 1988; Bolduan, 1988). Prohaszka and Baron (1980) also found the ABC-3 of a feed to increase as its protein content increased. In the present experiment, meat and fishmeal had the highest ABC and BUF values of all the organic ingredients. This was thought to be because of their high ash and protein contents. Jasaitis *et al.* (1987) also found these ingredients to have the highest ABC-4 values of all organic ingredients. The milk products category (in particular, rennet casein and spray dried skim) also had high ABC values. However, the other ingredients in this category had lower values. Again, this is believed to be related to the ash and protein contents.

Of the vegetable proteins, soyabean meal, Soycomil, rapeseed, and sunflower meal had the highest ABC values. Jasaitis *et al.* (1987) found that the geographic origin of an ingredient can affect its ABC because it influences the ion concentration of the ingredient and this may help to explain the variation in ABC values found for individual ingredients. Maize gluten and milo distillers meal were uncharacteristic of the vegetable protein group of ingredients in that they both had pH values less than 4.5 and their ABC values were low relative to the other ingredients in this group. Jasaitis *et al.* (1987) also found such fermented products to have some of the lowest ABC-4 values of the organic ingredients examined.

Cereals and some root and pulp products had low ABC and BUF values in the present experiment. This was in agreement with previous findings (Jasaitis *et al.*, 1987; Bolduan, 1988; Bolduan *et al.*, 1988 and BASF, 1989).

Acids were found to have negative ABC values. The use of organic acids in starter diets offers the opportunity of lowering diet ABC without having to reduce dietary protein or mineral content. However, the beneficial effects of organic acids on pig health are strongly dependent on the initial BUF value of the diet (Blank *et al.*, 2001). The organic acids of choice would be orthophosphoric, fumaric, formic or malic if the prime mode of action of these acids was deemed to be the lowering of diet ABC and increasing gastric acidity. However, acids for use in pig diets are often selected for other qualities also such as: antimicrobial effects on pathogenic bacteria, promotion of beneficial or probiotic bacteria, nutritional value, improved non-specific immunity (Pratt *et al.*, 1996), stimulatory effect on pancreatic secretion (e.g., lactic acid: Thaela *et al.*, 1998), physical form (dry or liquid), corrosive nature and safety.

In the literature, ABC-3 values were used by some researchers (Prohaszka and Baron, 1980) while ABC-4 values were used by others (Jasaitis *et al.*, 1987; Bolduan *et al.*, 1988). The present study found that these values for ingredients are well correlated within ingredient



The pH and acid-binding capacity of ingredients commonly used in post-weaning pig diets was measured.

categories with the exception of acids and acid salts. For this reason, it should matter little which measure is used. Great variation occurred within ingredient categories with regard to ABC and BUF values.

The ABC values of complete diets can be predicted if the ABC of each ingredient in the diet is known. The observed and predicted ABC values were well correlated. Jasaitis *et al.* (1987) also found this to be the case. The result is that diets can be formulated using the ABC values for ingredients presented here so that complete diets with low ABC values are produced. Such diets can be used when a high gastric pH is likely to be a problem (e.g., at weaning). These diets could also be employed as part of a strategy to reduce *E. coli* or *Salmonella* in older pigs. This is particularly important now due to recent EU bans on feed antibiotics in response to human fears of antibiotic resistant bacteria originating in animals (Barton, 2000; Bager *et al.*, 2000).

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