Organic acids in diets for entire male pigs: Effect on skatole level, microbiota in digesta, and growth performance

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Abstract

The effect of different organic acids in diets of entire male pigs on the concentration of skatole in colon, plasma, and adipose tissue and on the composition of the microbiota in the gastrointestinal tract was evaluated. Entire male pigs (n=60) of sows inseminated with boars disposition for high skatole levels (31.7 and 113.2 kg initial and final body weight, respectively) were fed either control, 1.0% formic acid, 0.85% benzoic acid, 0.85% sorbic acid, 1.2% fat coated Ca-butyrate, or 1.5% fat and inulin coated Ca-butyrate diets. All levels of organic acids corresponded to 0.85% of pure acid. Digesta samples from colon descendens were analyzed for skatole, indole, and organic acids. Digesta samples for microbiological examinations were taken from proximal jejunum, colon descendens, and rectum. There were no differences in levels of skatole, indole, or organic acid levels in colon descendens among pigs fed organic acid supplemented diets and control diet. Plasma skatole levels were significantly reduced in pigs fed diets containing formic acid or benzoic acid compared with the control, but supplementing diets with organic acids did not affect skatole levels in adipose tissue. Pigs fed organic acids had significantly lower levels of coliforms, enterococci, and lactic acid producing bacteria (LAB) in all sampling sites of the gastro-intestinal tract. Pigs fed 1.5% fat and inulin coated Ca-butyrate had less reduction in the number of coliforms and LAB in the small intestine compared with pigs fed formic, benzoic and sorbic acid. Formic acid had a stronger antibacterial effect on coliforms than benzoic or sorbic acids in the small intestine. Pigs fed diets containing formic acid, benzoic acid, or sorbic acid had significantly higher average daily gain and better feed conversion ratio (FCR) than the control pigs during the grower phase, and tended to improve FCR during the overall period. The inclusion of fat coated Ca-butyrate or fat and inulin coated Ca-butyrate had no effect on growth performance of the pigs. In conclusion, supplementing diets with different organic acids reduced number of coliforms, enterococci, and LAB in the gastrointestinal tract, but did not affect skatole levels in colon or adipose tissue of entire male pigs.

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Keywords: Butyrate; Organic acids; Entire male pigs; Skatole; Microbiota

1. Introduction

Concerns about animal welfare have led to restrictions on castration practices of male pigs in Norway and other European countries. A major problem with meat from...
entire male pigs is boar taint. Skatole (3-methylindole), a main compound leading to boar taint, is produced in the hind-gut of pigs by specialized bacteria (Yokoyama et al., 1977). L-tryptophan originating from the gut mucosa cell debris from the distal part of the gastrointestinal tract is the major precursor for microbial skatole formation (Yokoyama and Carlson, 1979; Claus et al., 1994). Skatole production in the hind-gut of pigs has been shown to be affected by several dietary factors. Addition of high levels of carbohydrates with low ideal digestibility such as chicory inulin (Rideout et al., 2004; Lanthier et al., 2006) or raw potato starch (Claus et al., 2003; Andersson et al., 2005; Lösel and Claus, 2005), which favors butyrate formation in the colon, has been shown to decrease skatole synthesis. Butyrate produced by bacterial fermentation in the colon has been shown to inhibit mucosal apoptosis (Mentschel and Claus, 2003) and thereby reduce the availability of endogenous tryptophan available for skatole production.

Antibiotic growth promoters have been shown to reduce microbial activity in the gastro-intestinal tract and to reduce the concentration of skatole in feces of gilts and entire male pigs (Hawe et al., 1992; Hansen et al., 1997). In January 2006, their use was prohibited in the European Union due to concerns about bacteria resistance to antibiotics. Organic acids have received much attention as an alternative and considerable research confirms positive effects on growth performance in all classes of pigs (Roth and Kirchgessner, 1998; Partanen and Mroz, 1999; Witte et al., 2000). Organic acids have shown to modify bacterial populations in the gastro-intestinal tract of pigs (Bolduan et al., 1988; Øverland et al., 2000; Canibe et al., 2001). It would be of interest to investigate whether the addition of organic acid to diets would reduce skatole synthesis in entire male pigs and reduce the boar taint problem of the meat. Furthermore, the effect of adding butyrate directly to diets on skatole production in hindgut has not been investigated. A study was designed to investigate the effect of different organic acids (formic acid, benzoic acid, sorbic acid, and butyrate) in diets of entire male pigs on 1) growth performance and carcass quality, 2) microbiota in gastro-intestinal tract, 3) skatole, indole, and organic acid levels in colonic digesta, and 4) skatole, indole, and androstenone concentration in blood plasma and adipose tissue.

2. Materials and methods

One feeding experiment evaluated different organic acids in diets of entire male pigs at the Experimental Farm of the Norwegian University of Life Sciences.

2.1. Animals, allotment and housing

A total of 60 entire male pigs [(Norwegian Landrace × Yorkshire) × (Norwegian Landrace × Duroc)] from 12 litters of sows inseminated with boars dispositioned for high skatole levels were used. Average initial weight was 31.7 kg and average final weight was 113.2 kg. The experiment was conducted as a randomized complete block design. Pigs were blocked by litter and allotted by initial weight to six dietary treatments with 10 replicates per treatment. The experimental period lasted on average 78 days. At feeding, each pig was restrained in an individual feeding stall until the feed was consumed in order to record individual feed intake. Thus, each pig was one experimental unit. The experiment was split into a growing period from start until 60 kg live weight, a finishing period from 60 kg live weight until slaughter, and the overall period. Pigs were housed in an environmentally controlled barn with partially slotted concrete floor. Ten 8.2 m² pens designed for individual feeding were used. Saw dust was provided as bedding. Average ambient daily temperature was 15.9 °C (range 14.0 °C to 19.0 °C).

2.2. Diets and feeding

The dietary treatments were: 1) a basal diet based on barley, wheat, oats and soybean meal, 2) basal diet+0.85% formic acid, 3) basal diet+0.85% benzoic acid, 4) basal diet+0.85% sorbic acid, 5) basal diet+1.2% normal coated Ca-butyrate, or 6) basal diet+1.5% inulin coated butyric acid. The normal coated butyrate (Greencab butyrate 70) contained approximately 70% butyrate-anion, 14% Ca and 25% fatty acids. The inulin coated butyrate contained approximately 50% butyrate-anion, 10.5% Ca, 15% fatty acids, and 25% inulin. The inulin source was Raftifeed® IPE from chicory root and contained a mixture of oligo- and polysaccharides, which are composed of fructose units linked by β(2-1) linkages with a terminal glucose unit. The degree of polymerization ranged between 2 and 60 fructose units. Levels of pure organic acids corresponded to 0.85% in all test diets. In the Ca-butyrate diets, adjustments were made for additional supply of Ca. Diets were formulated to meet or exceed the requirements for indispensable amino acids and all other nutrients (NRC, 1998).

A cumulative sample from each diet was taken for chemical analysis. The diets were similar in chemical composition with respect to macro nutrients (Table 1). The diets were calculated to contain the same level of Ca, but analysis revealed a higher Ca content in both butyrate diets compared with the control diet. The analyzed content of the respective organic acid was in the formic acid diet 10.5 g kg⁻¹, benzoic acid diet 7.8 g kg⁻¹, sorbic acid diet 7.1 g kg⁻¹, normal coated butyrate diet 8.2 g kg⁻¹, and inulin coated butyric acid diet 8.4 g kg⁻¹.

There were no major differences in buffering capacity among the diets, which were within the narrow range of 602 (control) to 620 (normal coated Ca butyrate) mEq.

All pigs were individually fed twice per day according to a restricted Norwegian feeding scale (Øverland et al., 2000). Feed refusals of each pig were recorded and subtracted from
the feed intake. All pigs were given free access to water from nipple drinkers. Feed consumption was recorded daily and body weight was recorded weekly to determine average daily gain (ADG), average daily feed intake (ADFI) and feed conversion ratio (FCR) as kg feed/kg gain.

2.3. Carcass characteristics

Pigs were slaughtered at a commercial slaughterhouse. All pigs received a normal morning meal the day of slaughter. They were slaughtered three to four hours post-prandial, when there was still feed in their gastro-intestinal tract. Carcass characteristics were measured after 1–2 d of chilling according to procedures described by Øverland et al. (2000). Dressing percentage was determined by: (hot carcass weight/final weight) × 100. Live weight was monitored at the day of slaughter. Carcass lean percentage was determined commercially on the slaughter line using a GP2Q pistol (Hennessy System Ltd., Auckland, New Zealand) to measure the depth of the longissimus dorsi and the backfat thickness at two sites (between the 10th and 11th rib, 6 cm from the midline and behind the last rib, 8 cm from the midline). A tracing of a cross section of the cutlet behind the last rib was made on tracing paper. The total area and meat area in the cutlet were determined by planimeter (Coradi AG, Zürich, Switzerland). The fat area of the cutlet was determined by the difference between the total area and meat area. The P2 backfat thickness was measured 8 cm from the midline behind the last rib using tracing paper and a ruler.

2.4. Sample collection

Blood samples were collected from all animals 2–4 days prior to slaughter for determination of skatole, indole, and androstenone levels. Approximately 8 ml blood was sampled by venipuncture (EDTA-vacutainers) in the jugular vein/bijugular trunk. The serum was centrifuged within 1 h after

Table 1
Composition (g kg⁻¹) and chemical content of diets

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>Formic acid</th>
<th>Benzoic acid</th>
<th>Sorbic acid</th>
<th>Butyric acid</th>
<th>Coated Butyric acid</th>
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<td>577</td>
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<td>Oats</td>
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<td>Cysteine</td>
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<tr>
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<td>2.11</td>
<td>2.16</td>
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<td>2.12</td>
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<tr>
<td>Buffering capacity, mEq</td>
<td>602</td>
<td>584</td>
<td>615</td>
<td>612</td>
<td>620</td>
<td>619</td>
</tr>
</tbody>
</table>

a Provided the following amounts per kilogram of feed: 105 mg Zn (ZnO); 75 mg Fe (FeSO₄ · H₂O); 60 mg Mn (MnO); 15 mg Cu (CuSO₄ x 5H₂O); 0.75 mg I (Ca(IO₃)₂); 0.3 mg Se (Na₂SeO₃); 9000 IU vitamin A; 1125 IU cholecalciferol; 112.5 mg dl-α-tocopherol acetate; 2.25 mg menadione; 5.625 mg riboflavin, 18.73 mg d-pantothenic acid; 22.5 μg cyanocobalamin; 22.5 mg niacin; 0.225 mg biotin; 1.69 mg folic acid; 364 mg choline.
sampling. Adipose tissue samples from the neck region were taken for determination of skatole and androstenone levels within 1 h after evisceration. All fat layers were represented in the samples. Samples were stored in a freezer at about −20 °C until analyses. Digesta samples for microbiological examination and determination of skatole, indole, and VFA were collected. The digesta sampling was performed on the day of slaughter when the pigs reached the commercial slaughter weight. The digestive tract was taken out on the slaughter line and the stomach and intestines were removed. The sample collection started immediately and all sampling was completed within 2–2.5 h after slaughter. Skatole, indole, and VFA concentration were determined in samples from colon descendens taken from the last meter proximal to the rectum. Microbiological examinations were performed in samples from 1) jejunum, 1 m distal to pylorus, 2) colon descendens, and 3) rectum, about 5 cm cranially from anus. Samples with a volume of 5 to 20 ml were poured into plastic 50-ml Falcon tubes (Corning Incorporated, Corning, N.Y.); the collected contents were kept on ice until inoculation and incubation. The samples were processed within 1 to 3 h after collection. They were weighed and serially diluted in 0.9% saline, and 0.1 ml of each sample was plated on selective media.

2.5. Bacterial counts from intestinal samples

*Clostridium perfringens* was grown on 5% blood agar (MERCK 10886) anaerobically at 37 °C for 48 h with MERCK Anaerocult A. Lactic acid producing bacteria (LAB) were grown on MRS-lactobacillus agar (MERCK 10660) aerobically at 37 °C for 72 h. *Enterococcus* spp. was grown on MacConkey agar (MERCK 5465) aerobically at 37 °C for 24 h. The figures from the bacterial counts were recorded as CFU/g digesta (Swanson et al., 1992). In a few cases, the dilution ranges chosen for isolation (coliforms in jejunum 10^{-2}, 10^{-3} and 10^{-4}, in colon and rectum 10^{-3}, 10^{-4} and 10^{-5}; enterococci in jejunum 10^{-2}, 10^{-3} and 10^{-4}, in colon and rectum 10^{-2}, 10^{-3} and 10^{-5}; LAB 10^{-2}, 10^{-3}, 10^{-5}, 10^{-6} and 10^{-7}, in colon and rectum 10^{-5} 10^{-6}, 10^{-7}, 10^{-8} and 10^{-9}; *C. perfringens* in jejunum 10^{-2} and 10^{-3}, in colon and rectum 10^{-2}, 10^{-3} and 10^{-4}) were either under (two samples for coliforms and one sample for enterococci) or overestimated (two samples for coliforms, 66 samples for enterococci and four samples for LAB). It was not practical to use undiluted or 10^{-1} diluted digesta for spreading on agar plates because of consistency of the material. When the bacterial concentrations were lower than our minimal detection level (10^{-2}), a log_{10} of 1.9 was registered. In cases of higher bacterial counts than the dilutions permitted to count, a log_{10} value of 1 higher than highest dilution was set as the count value.

2.6. Chemical analysis

Crude protein (Kjeldahl-N x 6.25; EU Dir 93/28), crude fat (HCl hydrolysis with petroleum ether extraction; method B in EU Dir 98764/EC), dry matter (EU Dir 71/393), crude fiber (EU Dir. 92/89), and ash (EU Dir 71/250) in the diets were analyzed. Phosphorus and calcium content of the diets were analyzed by atomic absorption spectrophotometry according to methods described by AOAC (1990). Analyses of amino acids were carried out according to Directive 98/64/EC (OJEC, 1998). Buffering capacity in the diets was analyzed according to the method described by Prohásza and Baron (1980), and expressed as milliequivalents (mEq) of 1.0 N HCl required to obtain pH 3 in 1 kg sample. Skatole level in adipose tissue was measured by the spectrophotometric method described by Mortensen and Sørensen (1984). For each set of samples, corresponding to the day of slaughter, several skatole standards were analyzed with the results within pre-described tolerance limits. Determination of skatole and indole in extracted fat was also carried out by HPLC using fluorescence detection according to a method developed by Gibis (1994). The HPLC equipment used was from Agilent Technologies agilent.com/chem/1100, Agilent 1100 Series. Detection limit was 0.005 μg/g for both skatole and indole. Androstenone level in adipose tissue was measured by a time-resolved fluorimunoassay described by Tuomola et al. (1997), modified by using antiserum produced and characterized by Andresen (1974).

The concentration of skatole and indole in the digesta was measured by HPLC according to method described by Jensen and Jensen (1994) and the chromatographic conditions used were as outlined by Hansen-Møller (1994). Contents of organic acids in digesta were measured by a modification of the capillary gas chromatography method as described by Jensen et al. (1995).

2.7. Statistical analyses

Statistical analyses on growth performance, carcass characteristics, androstenone, skatole, indole and organic acid levels and microbiota in digesta were performed using the GLM procedure of SAS (1990) for a complete randomized block design. Each pig was the experimental unit. Results are presented as the least square mean for each treatment, and variance is expressed as standard error of the mean (S.E.M.). Means were separated according to the Ryon–Einot–Gabriel–Welch multiple range test. Significant difference among treatments was shown as P<0.05, tendency for difference was defined as P between 0.05 and 0.10, while not significant differences (NS) were shown as P>0.10. For microbiota in digesta, orthogonal contrasts were performed to compare differences among organic acids across intestinal sampling sites and to compare differences in microbial populations among sampling sites.

2.8. Animal care

All pigs were cared for according to laws and regulations controlling experiments with live animals in Norway (the Animal Protection Act of December 20th, 1974, and the
3. Results

3.1. Health

The pigs had a good health status. No health problems related to the dietary treatments were encountered during the experimental period. One pig from the group with benzoic acid diet was euthanized due to severe vomiting and appetite failure. No abnormalities were revealed at necropsy. One pig was removed from the sorbic acid diet due to paralysis in the hind legs caused by initial tail biting and secondary bacterial infection of the lower spine.

3.2. Androstenone, skatole, indole, and organic acid levels

There were no significant differences in the levels of skatole, indole, or organic acids in colon between the control pigs and pigs fed the organic acid supplemented diets; however, pigs fed inulin coated butyrate diets had the highest numerical levels of butyric acid in digesta (Table 2). Sorbic acid resulted in a significant lower concentration of butyric acid in colon compared with the two butyrate supplemented diets.

The addition of organic acids to the diet had no effect on the concentration of skatole or indole in adipose tissue, but significantly influenced the level of skatole in blood plasma of pigs (Table 3). Pigs fed diets containing formic acid or benzoic acid had significantly lower plasma skatole levels than pigs fed the control and the sorbic acid diets. There were no significant differences in androstenone levels in adipose tissue between the control and the organic acid supplemented diets. Pigs fed diets containing formic acid, however, had significantly lower androstenone levels in adipose tissue than pigs fed the benzoic acid, or the normal butyrate and inulin coated butyrate diets.

3.3. Microbiological determination in the gastrointestinal tract

Analyses of variance revealed that pigs fed organic acids in general produced lower counts of all four groups of bacteria analyzed in the intestine compared with the control pigs (Table 4). The numbers of *C. perfringens* in jejunum were often below the detection limit of the plating method, and were therefore not included in the statistical evaluations of the difference between each of the organic acid supplements. In colon and rectum, the numbers of *C. perfringens* were also at a low level and there seemed to be no conclusive
differences among the groups. There was no significant interaction between dietary treatment and segment for any of the parameters measured. In jejunum, all organic acid supplemented diets significantly reduced the number of coliforms compared with the control. The addition of benzoic or sorbic acid significantly reduced the number of enterococci and sorbic acid significantly reduced the number of LAB compared with the control. In colon, formic, benzoic, or sorbic acid significantly reduced the number of coliforms and LAB compared with the control while normal coated butyrate or inulin coated butyrate had no significant inhibitory effect. In rectum, the addition of formic acid or benzoic acid to diets significantly reduced the number of coliforms while the addition of benzoic and sorbic acid significantly reduced the number of LAB compared with the control.

When using orthogonal contrasts, pigs fed the normal and inulin coated Ca-butyrate diets had less reduction \((P<0.05)\) of coliforms and LAB in intestine compared with pigs fed diets supplemented with benzoic formic or sorbic acid. Formic acid had a stronger inhibitory effect on coliforms in all three parts of the intestine than benzoic acid or sorbic acid \((P<0.001)\). This was not the case for enterococci and LAB. In general, there was a lower level of microbiota in the proximal part of jejunum compared with colon and rectum \((P<0.001)\), but there were no differences between colon and rectum.

### 3.4. Growth performance and carcass traits

During the growing period, there were significant effects on ADG and FCR among diets (Table 5). Pigs fed diets containing formic acid and sorbic acid had a significantly higher ADG than the control pigs and the pigs fed both butyrate diets. Dietary addition of formic acid, benzoic acid and sorbic acid significantly improved FCR compared with pigs fed the control. Formic or sorbic acid gave significantly better FCR compared with the butyrate diets. During the overall period, dietary addition of organic acids had no effect on ADG or feed intake of pigs, but FCR tended to be improved with the addition of formic acid, benzoic acid, or sorbic acid to diets. Adding normal coated or inulin coated butyric acid to diets had no effect on growth performance of pigs during the grower or overall period. There were no significant differences among treatments for carcass weight or carcass lean percentage, but dressing percentage was significantly higher in pigs fed the benzoic acid diet compared with the control and the other diets added organic acids.

### 4. Discussion

The main objective of this study was to evaluate the effect of organic acids (formic acid, benzoic acid, sorbic acid and butyrate) on the production of skatole in the gastro-intestinal tract of entire male pigs. Organic acids have shown to exert an antimicrobial effect in the gastro-intestinal tract of pigs (Eckel et al., 1992; Gedek et al., 1992; Maribo et al., 2000). It was therefore hypothesized that organic acids would suppress the skatole forming bacteria in the hind-gut of the entire male pigs and thereby reducing the skatole formation.

Earlier findings have shown that feeding diets containing raw potato starch (Claus et al., 2003; Andersson et al., 2005; Zamaratskaia et al., 2005) or inulin (Rideout et al., 2004), favor butyrate formation in
the hind-gut. It has been suggested that butyrate present in the hind-gut inhibits mucosal apoptosis (Hass et al., 1997; Mentschel and Claus, 2003) and thereby reduce the availability of endogenous tryptophan for skatole production (Mentschel and Claus, 2003). The intention of the present experiment was to evaluate if supplementing diets with butyrate directly, rather than through stimulating formation of butyrate in the hind-gut by use of carbohydrates with low ileal digestibility, would reduce the formation of skatole. Two different types of butyrate were chosen; one fat coated Ca-butyrate and one inulin coated Ca-butyrate. By coating butyrate with

Table 5
Effect of dietary organic acid addition on growth performance and carcass traits of entire male pigs

<table>
<thead>
<tr>
<th>Diets</th>
<th>Control</th>
<th>Organic acids</th>
<th>S.E.M.</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Formic acid</td>
<td>Benzoic acid</td>
<td>Sorbic acid</td>
</tr>
<tr>
<td>No. of pigs</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>9</td>
</tr>
<tr>
<td>Initial weight, kg</td>
<td>31.91</td>
<td>31.87</td>
<td>31.96</td>
<td>31.55</td>
</tr>
<tr>
<td>Final weight, kg</td>
<td>114.0</td>
<td>113.1</td>
<td>114.0</td>
<td>111.0</td>
</tr>
</tbody>
</table>

1Clostridium perfringens was not tested statistically because most values were below the detection limit (100 CFU/g digesta).
2Standard error of means.
3Means in a row with different superscript differ significantly (P<0.05).

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inulin, its release is steered towards the hind-gut of the pigs because the majority of inulin will be broken down by the microflora in the hind-gut (Rideout et al., 2004).

Supplementing diets with organic acids did not reduce skatole or indole levels in digesta, plasma or adipose tissue of entire male pigs. Supplementing diets with butyrate only gave a slight increase in butyrate level in colon from 65.1 in the control to 71 and 74.3 mmol kg$^{-1}$ DM in the Ca-butyrate and inulin coated Ca-butyrate diets, respectively. Butyrate supplementation did not affect skatole levels in the colon. Conversely, feeding raw potato starch (Claus et al., 2003; Zamaratskaia et al., 2005) or inulin (Rideout et al., 2004) as sources of fermentable carbohydrates has shown to decrease skatole synthesis in pigs. Claus et al. (2003) reported that feeding pigs with 578 g kg$^{-1}$ DM raw potato starch gave an increase in butyrate in feces from 63 mmol kg$^{-1}$ during the reference period to 136 mmol kg$^{-1}$ during the test period. Rideout et al. (2004) reported a numerical increase in butyrate levels in feces from 2.67 mmol kg$^{-1}$ DM in the control pigs to 3.81 mmol kg$^{-1}$ DM in pigs fed diets supplemented with 50 g kg$^{-1}$ chicory inulin extract. These authors concluded that dietary supplementation of 50 g kg$^{-1}$ chicory inulin extract was effective in decreasing the fecal excretion of skatole. In the present experiment, the inulin coated butyrate diet provided 3.75 g chicory inulin per kg of diet, which is much lower than the levels used by Rideout et al. (2004). Thus, the inulin provided by the inulin coated butyrate diet was not expected to noticeably influence the butyrate levels or skatole formation in the colon. These findings indicate that feeding inulin or raw potato starch is more effective in increasing the butyrate level in the hind-gut of pigs than supplementing butyrate to diets directly. The effect of feeding inulin or raw potato starch on the formation of butyrate depends, however, on the level used. In these cases, very high levels were used, while the level of butyrate supplemented in the diets in the present experiment was low. Adding chicory inulin or raw potato starch to diets may also reduce skatole production by other mechanisms than through increased formation of butyrate. This may include increased incorporation of tryptophan into microbial biomass, leading to a decreased level of tryptophan available for skatole production, or altered hind-gut conditions which result in a decreased rate of absorption of skatole, as discussed by Claus et al. (2003) and Andersson et al. (2005). The higher numerical level of skatole in adipose tissue of the control pigs was a result of a pig with a skatole level of 0.92 μg g$^{-1}$. In the present experiment, 53.4% of the entire male pigs had androstenone levels above 1.0 μg g$^{-1}$ while 3.4% had skatole levels above 0.2 μg g$^{-1}$. These results indicate that the proportion of pigs with high androstenone levels and low skatole levels were relatively high. Levels of androstenone vary among breeds. The breed used in the present experiment was Noroc which consists of 50% Landrace, 25% Yorkshire, and 25% Duroc. The Duroc breed has shown to have a higher level of androstenone than Yorkshire and Landrace (Xue et al., 1996).

For the microbita analyses in the present experiment, the number of pigs in each group is relatively low compared with the variable nature of the results between the different organic acid. However, the statistical analysis support interesting differences among the different organic acid supplementations.

The antimicrobial effect of organic acids in the gastrointestinal tract of pig in the present study is in agreement with previous findings in pigs fed formic acid (Eckel et al., 1992; Gedek et al.,1992) or K-diformate (Overland et al., 2000; Canibe et al., 2001). A marked antimicrobial effect throughout the gastro-intestinal tract of piglets fed diets supplemented with benzoic acid has been observed (Maribo et al., 2000; Kluge et al., 2006). Sorbic acid has shown to have an antimicrobial effect in the intestinal microflora of broiler chickens (Sofos et al., 1985). A reduction in numbers of LAB has also been observed in chicken exposed to organic acids in the litter bedding (Garrido et al., 2004). The fact that the intestines of animals exposed to feed supplemented with organic acids presented lower counts of Lactobacillus spp. than in the control group is not a desired effect because of the regulatory and protecting role of these bacteria (Fukata et al., 1991). On the other hand, an inhibitory effect on the general population of bacteria in the gastro-intestinal tract increases the availability of dietary energy and nutrients to the host animal, resulting in increased growth rate and enhanced feed efficiency as discussed by Overland et al. (2000) and Canibe et al. (2001). The antimicrobial effect of organic acids did not coincide with changes in skatole production in the hind-gut in the present study. Lanthier et al. (2006) however, reported that changes in plasma skatole level of pigs post-weaning could be attributed in part to the post-weaning dynamics of the intestinal microflora.

The improvement in ADG and FCR of the pigs by supplementing diets with organic acids is in agreement with earlier observations (Partanen and Mroz, 1999; Roth and Kirchgeissner, 1998; Overland et al., 2000; Witte et al., 2000). The largest effect on growth performance was observed in pigs fed formic acid or sorbic acid, while the addition of Ca-butyrate or inulin coated butyrate did not improve growth performance. A
greater improvement in growth performance of pigs during the grower period than during the overall period was also reported by Kirchgessner et al. (1997) and Øverland et al. (2000). The high level of acid in the formic acid diet may have contributed to the improvement in growth performance. The high level of acid could be due to the presence of formic acid in the basal diet, because conventional swine diets contain about 0.05 g kg⁻¹ formate from natural sources. Another explanation for this could be analytical inaccuracy. The growth-promoting effect of organic acids observed in the present experiment, can partially be explained by the antimicrobial effect of the organic acids primarily in the small intestine. The lack of effect of the two butyrate supplemented diets on growth performance may be a result of the minor antimicrobial effect of these supplements in the small intestine. Claus et al. (2007) on the other hand, reported that fat coated Ca-butyrate improved digestive and absorptive capacities in the small intestine of pigs. Organic acid supplementation did not affect carcass quality of entire male pigs, except for an increased dressing percentage of pigs fed benzoic acid. The increase in dressing percentage by benzoic acid may be a result of an antimicrobial effect and a subsequent gut wall thinning effect and/or a lower weight of the digestive tract as reported by Visek (1978) for antimicrobial growth promoters.

5. Conclusion

Supplementing diets with formic acid, benzoic acid, sorbic acid, or normal coated or inulin coated butyric acid did not affect skatole or indole levels or organic acid levels in colon of entire male pigs. Formic acid or benzoic acid supplemented diets resulted in lower plasma skatole levels than the control or the sorbic acid supplemented diets. Adding formic acid, benzoic acid, sorbic acid to diets for entire male pigs reduced microbial population in the gastro-intestinal tract, but this did not coincide with changes in skatole production in the hind-gut.

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