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Effect of different dietary strategies on gas emissions and growth performance in post-weaned piglets

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Abstract

The objective of this study was to assess the effects of different dietary strategies in post-weaned piglets on gas emissions and animal performance. Eighty piglets were allotted in ten environmentally-controlled chambers. Piglets were fed with five different isoenergetic diets: control, low protein (LP), inclusion of sugar beet pulp (SBP), addition of benzoic acid (BA) and a combination of LP, SBP and BA (LP + SBP + BA). The gases analyzed were ammonia (NH_3), methane (CH_4), nitrous oxide (N_2O) and carbon dioxide (CO_2). For NH_3, the most effective treatment was LP, with a reduction of 61%. The LP + SBP + BA reduced NH_3 emission by 51%, the inclusion of SBP by 43% and the least effective technique was BA, which decreased by 9.5%, compared to control. The CH_4 emission was reduced by 30% for LP, but was increased by 23% for SBP and 24.6% for LP + SBP + BA. Benzoic acid did not differ from control group. The N_2O emission did not show statistically differences, and CO_2 and carbon dioxide equivalent (CO_{2eq}) emission increased with LP + SBP + BA (14 and 15% respectively), but were not affected by other diets. No effect of dietary treatment was observed on the growth performances compared with control group ($p > 0.05$). We can conclude that the best technique to reduce NH_3 emission was LP. Inclusion of SBP decreases NH_3 emission, but can increase greenhouse gas emissions. It would be interesting to evaluate the effect of higher percentages of BA because the promising results. Combining techniques is not a good strategy to obtain an additive effect in gas emissions reduction.

Additional key words: pig production; aerial pollutants; protein; benzoic acid; sugar beet pulp.

Introduction

Livestock production in confinement facilities results in gas emissions such as ammonia (NH_3), methane (CH_4), nitrous oxide (N_2O) and carbon dioxide (CO_2). In pig production, NH_3, CH_4 and N_2O are products of manure decomposition while CO_2 is primarily a product of animal metabolism. Ammonium (NH_4^+), under acidic or neutral pH conditions or NH_3 at higher pH levels, contribute directly to fine particulate matter and, once removed, to ecosystem fertilization, acidification and eutrophication (NRC, 2003). Excess deposition of reactive nitrogen can decrease the biodiversity of terrestrial ecosystems (NRC, 1997). Regarding greenhouse gas (GHG) emissions, CH_4 due to its long residence time (~8.4 years), becomes globally distributed and contributes to global warming with a global warming potential 21 times that of CO_2 (IPCC, 2006). The N_2O, once emitted, is globally distributed because of its long residence time (~100 years); it contributes to both tropospheric warming and stratospheric ozone depletion (IPCC, 2006). The CO_2 is produced during the oxidation process of carbon compounds in metabolic processes. Increasing the efficiency of nutrient utilization can be expected to decrease CO_2 production (Clark *et al.*, 2006).

During recent years, different dietary strategies have been successfully assessed to reduce gas emissions in piglet production. Several studies have demonstrated

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Abbreviations used: AA (amino acid); ADFI (average daily feed intake); ADG (average daily gain); BA (benzoic acid diet); BW (body weight); CO_{2eq} (carbon dioxide equivalent); CON (control diet); CP (crude protein); FCR (feed conversion ratio); GHG (greenhouse gas); LP (low protein diet); NSP (non-starch polysaccharides); SBP (sugar beet pulp diet).

that lowering dietary protein levels has strong effect on NH_3 emission (Latimier & Dourmad, 1993; Canh *et al.,* 1998a; Zervas & Zijlstra, 2002; Le *et al.,* 2008). This is based on an average of 8% reduction in N excretion per unit of crude protein (CP) reduction (Kerr, 1995; Hobbs *et al.,* 1996; Canh *et al.,* 1998a), and would give similar piglet performance if diets are balanced in essentials amino acids (AA) (Hansen *et al.,* 1993; Le Bellego & Noblet, 2002).

Inclusion of non-starch polysaccharides (NSP) into swine diets also shifts nitrogen excretion from urine to feces (Canh *et al.,* 1997). Because of fecal nitrogen is less easily degraded to NH_3, the inclusion of SBP into grow-finishing diets results in a linear relationship between the NSP intake and the NH_3 emission, decreasing by 5.4% for each 100 g increase in the intake of dietary NSP (Canh *et al.,* 1998b). However, digestibility of nitrogen and energy can be reduced by the inclusion of sugar beet pulp in pig diets (Chabeauti *et al.,* 1991; Zervas & Zijlstra, 2002), thus affecting animal performance.

On the other hand, Cortus (2006) observed that urinary pH has a major impact on the volatilization potential of NH_3. As pH is reduced, the NH_4^+ concentration increases and NH_3 concentration decreases within a solution. The pH of urine can be lowered by adding acidifying components to the diet, *e.g.* benzoic acid. These effects have been proven especially for pigs (Martin, 1982; Guiziou *et al.,* 2006; Aarnink & Verstegen, 2007). In addition, according to several authors, the environmental benefits of these different dietary techniques could be additive (Shriver *et al.,* 2002; Zervas & Zijlstra, 2002).

The objective of this study was to assess the effects of different dietary strategies (CP reduction, benzoic acid inclusion, sugar beet pulp supplementation and their combination) in post-weaned piglets on gas emissions, animal performance, water consumption and manure production and composition.

Material and methods

Experimental animals

A total of 80 (Yorkshire × Landrace) × Duroc piglets of 30 days of age, from a pig breeding company, were allotted in ten environmentally-controlled chambers based on sex (4 entire males and 4 females were caged together in each chamber). Pigs were allotted to 1 of 5 dietary treatments based on body weight (BW) in a randomized complete block design (2 pens per treatment and 8 pigs per pen). All pigs were fed a commercial prestarter diet for and adaptation period of 1 week prior to the start of the experiment, to allow the pigs to become accustomed to the chambers. At day 0 of the study, the mean age of the piglets was 37 days and initial BW was 13.1±2.37. The experiment lasted 28 days, until pigs were 65 days of age.

Treatments were as follows: 1) control diet-CON, 19.7% CP, 2) dietary inclusion of sugar beet pulp-SBP, 19.7% CP, 3) low protein diet-LP, 16.6% CP, 4) addition of benzoic acid-BA, 19.7% CP, and 5) a combination of LP, SBP and BA-LP + SBP + BA; 16.6% CP. Benzoic acid was provided by a commercial company (VevoVitall®; DSM Nutritional Products Ltd., Basel, Switzerland) and used at the manufacturer's recommended dose (5 mg per kg of feed). Diets were formulated to meet or exceed established nutrient requirements (NRC, 1998; Table 1). Diets were isoenergetic and digestible lysine was also constant among them. Each chamber was equipped with a 2-hole self-feeder and a nipple waterer allowing *ad libitum* access to feed and water. Pigs were individually weighed and feed disappearance controlled at days 0, 7, 14, 21 and 28 experimental days, to calculate average daily gain (ADG), average daily feed intake (ADFI) and feed conversion ratio (FCR) in each phase. In each chamber, also the water consumption was measured at each drinker by precalibrated water meters (C-700 polymer ABB, Atlantic Liquid Meters, Ontario, Canada).

Environmental chambers

The experiment was developed in ten environmentally controlled chambers, located at IRDA, Deschambault, Quebec. The chambers had width, length, height dimensions of 1.14 m, 2.44 m and 2.44 m, respectively. All the joints in the chambers and along the manure storage area were sealed. The door hardware ensured that the doors were sealed when closed. The flooring was fully slatted with the manure being stored in a shallow pit located under the floor. The manure was removed by a vacuum pump on days 7, 21 and 28 of experiment, weighed and sampled.

The ventilation system consisted of an inlet and exhaust fan mounted in the ceiling of each chamber.

Table 1. Diet formulation

	CON[1]	SBP	LP	BA	LP + SBP + BA
Ingredients (%)					
Barley	29.8	25.7	35.0	30.0	29.9
Corn	24.8	19.1	23.4	24.0	19.9
Wheat	14.2	14.0	18.1	14.1	16.1
Sugar beet pulp	0.0	10.0	0.0	0.0	10.0
Extruded soybean	9.50	9.41	6.89	9.68	8.60
Soybean meal 48%	12.0	12.1	7.1	12.0	5.90
Fat	2.19	2.10	3.40	2.20	2.80
Fish meal	3.78	3.80	2.00	3.79	2.00
Dicalcium phosphate	1.01	1.00	1.00	1.01	1.00
Calcium carbonate	0.81	0.83	0.81	0.81	0.81
L-Lysine HCl, 78%	0.61	0.61	0.80	0.61	0.81
Benzoic acid	0.00	0.00	0.00	0.50	0.50
Salt	0.39	0.40	0.41	0.40	0.42
Methionine-OH, 88%	0.08	0.12	0.17	0.09	0.20
L-tryptophan	0.09	0.10	0.19	0.09	0.20
L-threonine	0.06	0.08	0.12	0.06	0.13
Choline	0.09	0.10	0.09	0.09	0.10
Premix vit-min[2]	0.56	0.56	0.56	0.56	0.55
Total	100	100	100	100	100
Calculated nutrient concentration (%)					
Digestible energy (MJ kg^{-1})	14.64	14.56	14.64	14.56	14.56
Crude protein	19.7	19.7	16.6	19.7	16.6
Crude fibre	3.8	5.5	3.8	3.8	5.5
SID[3] lysine	1.14	1.14	1.14	1.14	1.14
SID methionine	0.42	0.42	0.42	0.42	0.42
SID methionine + cysteine	0.69	0.69	0.69	0.69	0.69
SID threonine	0.73	0.73	0.73	0.73	0.73
SID tryptophan	0.25	0.25	0.25	0.25	0.25

[1] CON: Control; SBP: Inclusion of sugar beet pulp; LP: Low protein diet; BA: addition of benzoic acid; LP + SBP + BA: combination of LP, SBP, and BA. [2] Premix vit-min supplied per kg final feed: Vitamin A: 12,000 IU; Vitamin D_3: 2,000 IU; Vitamin E: 40 mg; Vitamin K_3: 2.0 mg; Vitamin B_1: 3.0 mg; Vitamin B_2: 4.0 mg; Vitamin B_6: 3.0 mg; Vitamin B_{12}: 20 mg; Nicotinic acid: 25.0 mg; Pantothenic acid: 15.0 mg; Biotine 125 mg ; Choline chloride: 200 mg; Fe: 60 mg (as $FeCO_3$); Mn: 45.0 mg (as MnO); Zn: 120 mg (as ZnO); Cu: 135.0 mg (as $CuSO_4 \cdot 5H_2O$); Co: 0.50 mg (as $2CoCO_3 \cdot 3\,Co(OH)_2 \cdot H_2O$); I: 1.0 mg (as KI); Se: 0.34 mg (as Na_2SeO_3); Ethoxyquin: 0.06 mg. [3] SID: standardized ileal digestible.

The exhaust fan was able to vary the airflow from 0.4 to 2.5 $m^3\ min^{-1}$, to keep room temperature in the expected ranges. The exhaust air was directed through a 204 mm iris orifice damper (Model 200; Continental fan manufacturer inc., Buffalo, NY, USA). Its accuracy was rated at ± 5%. Ventilation was measured once every 2 h.

A differential pressure transducer measured the pressure across the orifice plate. The relationship between airflow and pressure was:

$$Q = 127\,[P]^{0.5} \qquad [1]$$

where Q = exhaust airflow, L s^{-1}; and P = differential pressure, cm H_2O.

The inlet air could be preheated by an induction heater. The operation of the heater and the ventilation fan were controlled by a temperature controller (EVS-22HA; Norsol Electronics, St-Hubert, Qc, Canada). The minimum ventilation rate was adjusted to 14 L s^{-1} in each chamber. The temperature in the chambers varied from about 25°C on day 1 of experiment (with 37 days of mean age) to 23°C on day 28. Lighting was provided at an intensity of 70 lux at 2.3 m from the floor from 7:00 h to 19:00 h.

Gas emissions

Relative humidity and temperature in the chambers were measured by a combined temperature and relative humidity probe (Model CS500, Campbell Sci., Logan, UT, USA) which was calibrated by a mercury thermometer (±0.4°C) and with a saturated aqueous salt solution. The dew point of the incoming air was available from the inlet ambient temperature and relative humidity values. The output from the temperature and relative humidity probe and the pressure differential transducer were recorded every 10 min by an acquisition system (Model CR-10, Campbell Sci., Edmonton, AB, Canada).

The sampling air was pumped through Teflon™ tubing until the laboratory, placed in the room beside the chambers. In this laboratory, CH_4, CO_2 and N_2O were analyzed by gas chromatography (model 3600, Varian, Walnut Creek, CA, USA). The strategy for chromatographic analysis was the separation of the three gases in columns packed with Porapak Q (Waters Corporation, Milford, MA, USA). The CH_4 was quantified with a flame ionisation detector while the CO_2 and N_2O were measured with an electron capture detector. The instrumental errors on CO_2, CH_4 and N_2O concentrations were ±30, 0.5 and 0.1 ppm, respectively. The NH_3 was analyzed by a non-dispersive infrared spectroscopy (Model 7MB2121, Siemens Ultramat, Willer eng. Montreal, Canada). The NH_3 concentration error was ±1.5 ppm.

The gas chromatograph analyzed the gases (CH_4, CO_2 and N_2O) circulating in the injection loop of the instrument at the end of each 10-min period. Then the sample was drawn from the next sampling location. The NH_3 concentration was an average of the concentrations of NH_3 in the sample air drawn during the last minute of the 10-min period. The flow rate of the sampling pump (Model PU356-N05.16, KNF Neuberger, USA) was ±2 L min^{-1}. All gas concentration measurements (mg m^{-3}) were taken continuously during the entire experiment included the concentration in the incoming air of the rooms. Calibration GHG measurements were taken once a day at 0:00, and were synchronized with the ventilation flow rate.

Cellulose fibre filters were placed at the end of each sampling Teflon™ tubes (6.4 mm diameter) to prevent dust particles from damaging the gas analyzers. To prevent condensation in the tubes, the conduit carrying the gas sampling tubes was ventilated by air maintained at 35°C. To maintain similar flow conditions, all tubes had a length of 25 m.

To obtain gas emissions, the following equations were used:

$$E_{gas} = \frac{\left(C_{gas\,out} - C_{gas\,in}\right)}{10^6} \cdot \left(\frac{\beta_{gas} \cdot Q \cdot 86400}{M_{pig}}\right) \cdot 10^6 \qquad [2]$$

where E_{gas} = gas emissions (mg_{gas} day^{-1} kg_{pig}^{-1}); $C_{gas\,out}$ = gas concentration in the room measured close to the air extraction: exhaust air (mg m^{-3}); $C_{gas\,in}$ = gas concentration outside, measured close to the chambers: inlet air (mg m^{-3}); β_{gas} = mass of gas by air volume (kg_{gas} m^{-3} air); Q = room ventilation rate (m^3 air s^{-1}); M_{pig} = total mass of the pigs in the room (kg); and 86400 s d^{-1} = 24 h d^{-1} · 3600 s h^{-1}.

Mass of gas by air volume:

$$\beta_{gas} = D_{gas} \cdot \rho_{air} \qquad [3]$$

where ρ_{air} = air density (1.2 kg_{air} m^{-3} air); D_{gas} = specific gravity (kg_{gas} kg_{air}^{-1}) at 101 kPa and 21°C and is equal to: NH_3 = 0.597; CH_4 = 0.55; CO_2 = 1.52; N_2O = 1.53.

Since gas concentrations are less accurate than their specific gravities and the temperatures during the study varied between 18 and 24°C, the specific gravities at 21°C and 1,013 bar were used for all periods.

Carbon dioxide equivalent (CO_{2eq}) was also calculated. This is a measure used to compare the emissions from various GHG based upon their global warming potential. The global warming potential for CH_4 over 100 years is 21, for N_2O is 310 and for CO_2 is 1 (IPCC, 2007).

Composition of manure

Total amount of manure was removed from each chamber weekly, and then homogenized by mechanical agitation. Three samples (500 mL) were taken from three random spots and mixed to get one final aliquot per chamber. The samples were immediately analyzed for dry matter content, pH, total nitrogen, ammonium nitrogen and minerals (total ashes, P, K, Ca, Mg, Na, Mn, Al, B, Cu, Zn and Fe).

Statistical analyses

For evaluation of the effect of dietary treatment on gas emissions and productivity data, the experimental unit was the chamber of 8 pigs. Growth performance data

Table 2. Mean temperature, relative humidity and airflow rates for the last 21 days

Diets[1]	Chamber	Temperature (°C)			Relative humidity (%)			Airflow (L s^{-1})		
		Week 1	Week 2	Week 3	Week 1	Week 2	Week 3	Week 1	Week 2	Week 3
CON	3	24.4	23.9	22.8	41	41	50	20	22	20
	7	24.6	24.0	23.3	41	41	47	20	16	18
LP	2	24.5	24.3	23.3	43	43	48	25	28	26
	10	24.2	24.0	23.3	40	40	46	15	15	16
SBP	5	24.6	23.8	23.3	44	44	51	20	19	20
	9	24.6	24.6	23.9	42	42	46	23	23	26
BA	4	24.6	24.0	23.2	39	39	45	18	16	15
	8	24.6	24.2	23.5	43	43	48	21	20	24
LP + SBP + BA	1	24.3	24.2	23.3	38	38	45	24	25	25
	6	24.6	24.0	23.5	42	42	44	21	18	20
Mean		24.5	24.1	23.3	41	41	47	21	20	21

[1] CON: control; LP: low protein diet; SBP: inclusion of sugar beet pulp; BA: addition of benzoic acid; LP + SBP + BA: combination of LP, SBP, and BA.

were subjected to analysis of variance, including dietary treatment as main effect and BW at day 0 as covariate. Gas emissions data were also subjected to analysis of variance as repeated measures, using the MIXED procedure. In this case, data were analyzed for the effects of dietary treatment, time (day) and their interaction. In both cases, the dietary treatment response was contrasted using the Tukey's test, and the significance level for all tests was set at $p < 0.05$. All calculations were performed using SAS software v. 9.0 (SAS, 2002).

Results

Ambient conditions

The temperature and relative humidity mean values per week for the dietary treatments during the last three weeks of the experiment are shown in Table 2. The mean temperatures and the relative humidity for each diet treatment were very similar for each week and treatment. Although the airflow rates did fluctuate during the day, the mean values resulted similar.

Gas emissions

The evolution of NH_3, CH_4, N_2O and CO_2 concentration during the trial, obtained for each treatment, is shown in Fig. 1a, 1b, 1c and 1d, respectively. Concentrations of all gases were kept in normal ranges in nursery piglets throughout the experimental period.

The higher NH_3 concentrations corresponded to CON and BA groups (2.67 and 2.55 mg m^{-3}, of mean NH_3 concentration during the experimental period, respectively). The LP and LP + SBP + BA diet presented lower concentrations (1.46 and 1.53 mg m^{-3}), and SBP had an average NH_3 concentration of 1.77 mg m^{-3}. The effect of removing the manure appears to explain the decreases occurring on days 7, 21 and 28 of the trial (Fig. 1a).

The mean CH_4 concentrations increased from 2.20 to 4.49 mg m^{-3} from week 1 to 4 (Fig. 1b). The LP and CON diets showed the lowest mean concentrations of CH_4 (2.69 and 3.15 mg m^{-3}, respectively) and BA the highest one (3.57 mg m^{-3}). Combination of treatments and SBP had a mean CH_4 concentration of 3.4 mg m^{-3} during the trial.

Overall N_2O concentration during the entire trial was 0.65 mg m^{-3}. Little change in N_2O occurred throughout the 4-week period (Fig. 1c), except during the last 7 days where a sudden increase (from day 21 to day 25) and subsequent decrease (on day 27) was observed. All treatments had similar N_2O concentration.

The mean CO_2 concentration differential was near 2890 mg m^{-3} for all the treatments. Over the 4-week period, the CO_2 concentration increased from 2100 to

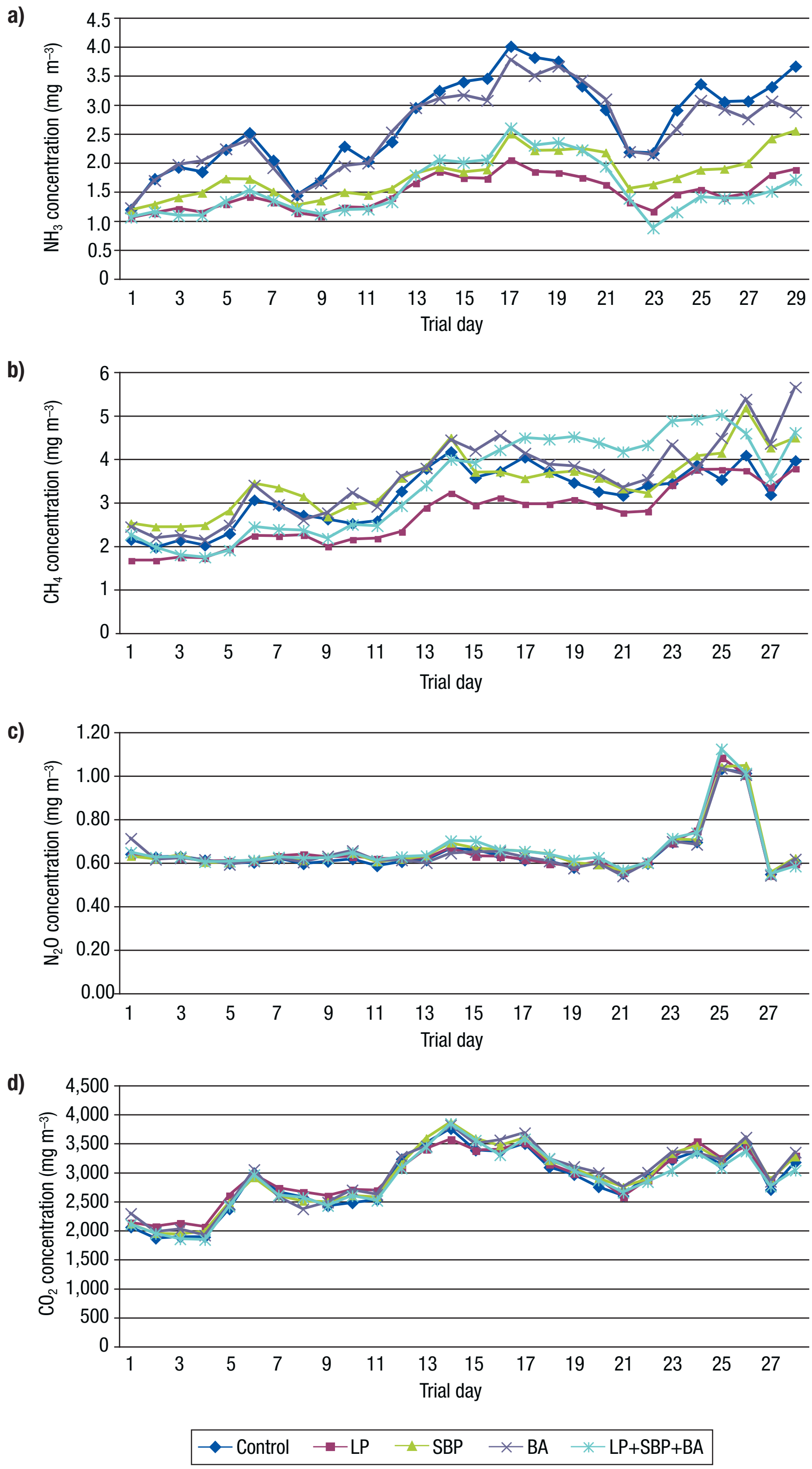

Figure 1. Evolution of ammonia (a), methane (b), nitrous oxide (c) and carbon dioxide (d) concentration (average net concentration of the two chambers for each treatment) during the trial (mg m^{-3}). Low protein (LP); inclusion of sugar beet pulp (SBP); addition of benzoic acid (BA); a combination of LP, SBP and BA (LP+SBP+BA).

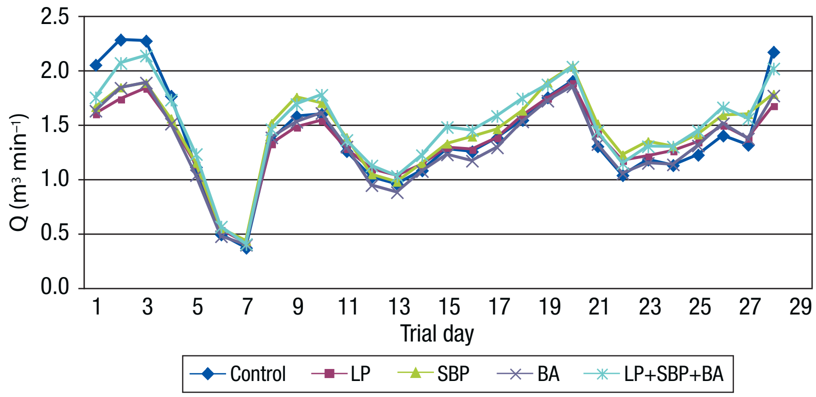

Figure 2. Evolution of ventilation rate of each chamber ($m^3\ min^{-1}$). Low protein (LP); inclusion of sugar beet pulp (SBP); addition of benzoic acid (BA); a combination of LP, SBP and BA (LP+SBP+BA).

Table 3. Effects of different dietary treatments on gas emission ($mg\ kg_{pig}^{-1}\ day^{-1}$)[1]

Gas	Diet[2]					SE[3]	*p*-value
	CON	LP	SBP	BA	LP + SBP + BA		
Ammonia	20.99[a]	8.03[b]	11.99[b]	18.99[a]	10.19[b]	0.687	0.0001
Methane	20.3[b]	14.1[c]	25.0[a]	22.7[ab]	25.3[a]	0.857	0.0001
Nitrous oxide	1.02	1.10	1.13	1.01	1.28	0.075	0.0813
Carbon dioxide	24,284[bc]	24,993[bc]	26,089[ab]	23,481[c]	27,829[a]	575	0.0001
GHG (CO_{2eq})[4]	25,028[bc]	25,630[bc]	26,966[ab]	24,273[c]	28,760[a]	590	0.0001

[1] Least squares means for two chambers, each with eight pigs. [2] CON = control; LP=low protein diet; SBP=inclusion of sugar beet pulp; BA=addition of benzoic acid; LP+SBP+BA=combination of LP, SBP, and BA. [3] SE = standard error. [4] CO_{2eq} = (methane emission · 21) + (nitrous oxide emission · 310) + carbon dioxide emission (IPCC, 2007). [abc] Mean values within a row lacking a common superscript letter differ significantly ($p < 0.05$)

3200 mg m^{-3} (Fig. 1d). All treatments had similar CO_2 concentrations. The effect of removing the manure appears to explain the decreases occurring on days 7, 21 and 28 of the trial (Fig. 1d).

Overall ventilation rate (Fig. 2) over the entire trial was 1.40 $m^3\ min^{-1}$, being similar for all treatments.

Mean gas emissions (mg kg $pig^{-1}day^{-1}$) of different dietary treatments are presented in Table 3. The four experimental diets evaluated decreased NH_3 emission in the trial with respect to the CON. The most effective treatment was LP diet, with a reduction of 61% compared with CON diet. Combination treatment obtained an NH_3 reduction of 51%. The inclusion of SBP reduced NH_3 emission by 43% and the least effective technique was the addition of BA, not differing statistically from the CON group.

However, CH_4 emission were reduced by 30% for LP compared to CON diet, but were increased by the inclusion of SBP (23%) and the LP + SBP + BA treatment (24.6%). The BA inclusion did not result in statistical differences.

Diet modification did not decrease N_2O emission in all different dietary strategies compared with CON group although, in any case, differences were significant.

With respect to the CO_2 emission, LP, SBP and BA diets did not differ from CON group, while LP + SBP + BA treatment increased CO_2 emission by 14% compared with CON diet.

The diets affected the CO_{2eq} emission in a similar way to the CO_2 emission, with no effect of the LP, SBP and BA diets and LP + SBP + BA treatment increasing CO_2 emission by 15%.

Animal performance

The growth performance of piglets fed with the different dietary treatments is shown in Table 4. Initial

Table 4. Effects of different diets on body weight (BW, kg) at day 0, 7, 14, 21 and 28 of the trial, and average daily gain (ADG, kg), average daily feed intake (ADFI, kg) and feed conversion ratio (FCR) per week

	Diet[1]					
	CON	**LP**	**SBP**	**BA**	**LP+SBP+BA**	**SE[2]**
BW0	13.12	13.22	13.10	13.33	12.94	0.072
BW7	17.24[ab]	17.13[ab]	17.49[a]	17.56[ab]	16.43[b]	0.184
BW14	21.94	21.78	22.06	21.94	20.46	0.360
BW21	27.08	26.89	27.27	27.91	25.11	0.962
BW28	31.97	31.34	33.42	32.05	31.38	1.519
ADG1 (week 1)	0.515[ab]	0.496[ab]	0.544[a]	0.553[ab]	0.417[b]	0.023
ADG2 (week 2)	0.586	0.581	0.574	0.606	0.506	0.040
ADG3 (week 3)	0.644	0.639	0.648	0.685	0.584	0.085
ADG4 (week 4)	0.612	0.557	0.773	0.517	0.785	0.074
ADG total	0.590	0.571	0.632	0.592	0.571	0.047
ADFI1 (week 1)	0.864	0.903	0.863	0.883	0.837	0.028
ADFI 2 (week 2)	1.008	1.040	1.050	1.012	1.059	0.030
ADFI 3 (week 3)	1.059	1.287	1.206	1.260	1.162	0.086
ADFI 4 (week 4)	1.306	1.162	1.593	1.158	1.771	0.206
ADFI total	1.062	1.099	1.176	1.076	1.207	0.075
FCR1 (week 1)	1.69[ab]	1.81[ab]	1.58[b]	1.60[ab]	2.03[b]	0.082
FCR 2 (week 2)	1.72	1.79	1.84	1.65	2.07	0.087
FCR 3 (week 3)	1.67	2.02	1.86	1.86	2.00	0.269
FCR 4 (week 4)	2.22	2.12	2.07	2.26	2.34	0.462
FCR total	1.82	1.94	1.84	1.85	2.11	0.170

[1] CON: control; LP: low protein diet; SBP: inclusion of sugar beet pulp; BA: addition of benzoic acid; LP + SBP + BA: combination of LP, SBP, and BA. [2] SE: standard error. [ab] Mean values within a row lacking a common superscript letter differ significantly ($p < 0.05$).

BW did not show statistical differences. No effect of dietary treatment was observed on the global performances of piglets ($p > 0.05$). However, BW and ADG were lower and FCR was higher in LP + SBP + BA dietary treatment than in SBP group after the first experimental week. None of the dietary treatments tested as feed strategies to reduce gas emissions showed statistical differences in growth performance compared with CON diet. Nevertheless these differences were attenuated during the subsequent days and no effect was observed thereafter.

Water disappearance

The water disappearance for each treatment consisted of both consumption and waste by the pigs. The water disappearance was similar for all dietary treatments and no significant differences were obtained (Table 5). Numerically, the LP+SPB+BA dietary treatment had lower water consumption. These pigs used about 3.93 L pig^{-1} day^{-1} over the 4-week period whereas those in the other treatments used over 5 L pig^{-1} day^{-1}.

Manure production and composition

Manure production (total kg) was measured on days 7, 21 and 28 by emptying the storage pits and weighing the contents. No differences were observed between treatments (data not shown), and numerically were similar between them, except in the LP + SBP + BA dietary treatment where the production was lower, associated with lower water disappearance with this diet.

The manure analysis of the weekly composite samples did not show significant differences. Nume-

Table 5. Water disappearance (L pig^{-1} day^{-1}) for each diet treatment[1] during the trial

Week	CON		LP		SBP		BA		LP + SBP + BA	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE[2]
1	2.88	0.47	3.38	0.16	3.09	0.02	3.22	0.58	2.29	1.09
2	4.25	0.78	4.48	0.00	4.71	0.64	4.60	0.17	3.72	1.65
3	6.21	1.13	6.04	0.91	6.11	0.84	6.77	0.32	4.54	1.92
4	7.80	1.52	6.16	1.37	7.51	0.76	8.46	0.72	5.16	1.73
Mean	5.29	1.63	5.02	1.07	5.36	1.34	5.76	1.56	3.93	1.48

[1] CON: control; LP: low protein diet; SBP: inclusion of sugar beet pulp; BA: addition of benzoic acid; LP + SBP + BA: combination of LP, SBP, and BA. [2] SE: standard error.

rically the CON group showed the highest pH value (7.2), similar to the BA treatment (7.1), and higher than pH of the rest of treatments (LP, SBM and LP + SBP + BA; 6.6, 6.6 and 6.0, respectively).

Treatments with LP in the diet (LP and LP + SBP + BA) had the lowest values of total nitrogen excretion (7.6 and 7.8 g pig^{-1} day^{-1}) and N-NH_4 (3.2 and 2.7 g pig^{-1} day^{-1}), respectively. Nitrogen excretion in SBP and BA was similar (9.5 and 9.8 g pig^{-1} day^{-1}) and higher than in control diet (8.6 g pig^{-1} day^{-1}). In any case, differences did not reach significance ($p > 0.05$).

Mineral content in manure was similar in all dietary treatments and no significant differences were observed.

Discussion

While the efficacy of feeding strategies to abate NH_3 emission from pigs has been widely studied, traditionally researchers have been little concerned with GHG emissions by piglets. However, GHG emissions appear to be directly related to nutrient efficiency in pigs, suggesting that better production efficiency is accompanied by reduced GHG emissions per kg of product (Clark *et al.,* 2006). Several strategies appear promising to improve nutrient efficiency. First, the intake of excess nutrients can be reduced toward the current nutrient requirement to keep growth performance. Examples of this strategy include the reduction of dietary CP content combined with AA supplementation (Lenis & Jongbloed, 1999; Han *et al.,* 2001). Another strategy is to improve nutrient digestion (mainly carbohydrate fractions) using feed additives, which leaves less substrate available for bacterial processes and the subsequent production of undesirable gases (Sutton *et al.,* 1996; Mackie *et al.,* 1998).

In general, diets have more protein than the animals' requirement, leading to unutilized protein. Reduction in dietary CP and at the same time supplementing most essential AA to maintain AA balance is expected to reduce NH_3 emission, without negative effects on pigs' performance. In this experimental trial, a reduction of the protein content (19.7% to 16.6%) decreased NH_3 emission by 61%, obtaining a higher efficacy than expected. This result is in accordance with the findings of several authors (Kerr, 1995; Hobbs *et al.,* 1996; Canh *et al.,* 1998a). Total nitrogen excretion was also reduced (12%), but by a lower proportion than NH_3 emission. The somewhat higher reduction of NH_3 emission compared to the reduction in ammonium content could be explained by the fact that the pH of the manure was lowered as well when dietary CP level decreased. Latimier & Dourmad (1993) and Canh *et al.* (1998a) also found similarity in the relative reduction in nitrogen excretion and NH_3 emission.

With few exceptions, 1% (absolute) reduction of dietary protein content has been found to reduce N excretion from pigs by approximately 10% (relative) (Canh *et al.,* 1998a; Lenis & Jongbloed, 1999). According to these results, in the present study, total N content in manure was reduced in LP dietary treatments by 10.4% (relative). However, high variability of this variable and low number of replicates used in the present experiment probably did not allow differences to reach significance.

This nutritional strategy likewise can also reduce GHG emissions, according to several studies (Lenis & Jongbloed, 1999; Han *et al*., 2001). Assuming the excreted N is fully converted to N_2O, the reduction in N excretion would reduce the CO_{2eq} when feeding the LP diet (Ball & Möhn, 2003). In this experiment, the LP diet reduced CH_4 emission, but N_2O and CO_2 emissions did not differ from the CON group, resulting in similar overall GHG emissions. Likely age and weight of animals directly affect magnitude of this response. In this sense, studies conducted by Lenis & Jongbloed (1999) and by Han *et al.* (2001) used adult sows and fattening pigs, respectively.

It was anticipated that reducing dietary CP while balancing the diets for essential AA would support similar piglet performance. Results obtained in growth performance in the present study confirm this statement, in agreement with Hansen *et al.* (1993) and Le Bellego & Noblet (2002). However, contrary to this, other authors as Nyachoti *et al.* (2006) found that BW and the overall ADG were reduced by feeding diets containing 19-17% CP compared with higher contents (21-23%). This was not the case in the current experiment, even using lower dietary CP content (16.6%). The discrepancies between results obtained in different studies may be explained by the differences in the age of piglets used. Nyachoti *et al.* (2006) used piglets weaned at an earlier age (18±1 days of age), but in the current study or in Le Bellego & Noblet (2002), piglets were weaned at 28-30 days of age. Likely, the apparent inconsistency in effect of dietary CP content with AA supplementation on the growth performance in some studies could be associated with deficiencies of other nutrients, including non-essential AA, which may become limiting factors in early-weaned piglets.

Inclusion of NSP as SBP reduced NH_3 emission, supporting the hypothesis that fermentable carbohydrates in the diet can influence the NH_3 emission from pig slurry. In this trial, the addition of SBP (10%) decreased NH_3 emission by 43%. Cahn *et al.* (1997; 1998b) performed different experiments with SBP and obtained similar results. The most profound effect on NH_3 emission was found when 15% SBP was included in the diet and NH_3 emission decreased by 40%. However, the CH_4 emission increased with SBP dietary inclusion, in this due to both enteric and manure CH_4 production (Clark *et al.,* 2006). In fact, the amount of NSP in swine diets is clearly linked to enteric CH_4 production (Jensen, 1996). Zhu *et al.* (1993) observed an increase of CH_4 production following increasing levels of SBP.

Piglet performance was not affected by the use of SBP diet at the end of the study, according to Clark *et al.* (2006) but contrary to other authors (Chabeauti *et al.,* 1991; Zervas & Zijlstra, 2002). Zervas & Zijlstra (2002) included higher amount of SBP (20%), but used pigs with higher BW (23.7 kg at day 0). Ability to digest NSP components increases with age of pigs, since grower and finisher pigs can utilize dietary fiber better than young piglets (Choct *et al.,* 2010), then not affecting growth rate.

The use of BA diet in pigs may result in lowering the buffering capacity of diets, and subsequently in increasing the acidity of urine. The latter effect is due to a metabolic transformation of the anionic part into hippuric acid voided in urine. A lowered urinary pH is preferable from the environmental point of view because indoor volatilization of NH_3 (Mroz *et al.,* 1996). In the current experiment, inclusion of BA did not reduce NH_3 emission, contrary to other authors (Sauer *et al.,* 2008) and neither did it affect manure pH. The proportion of BA added to the diet (0.5%) was lower than the used by Sauer *et al.* (2008), who added 2% of BA to obtain a reduction in urine pH from 7.32 to 5.32. According to the present study, Guiziou *et al.* (2006) did not observe any effect on manure pH after 1% BA dietary inclusion. It is possible that, with a higher proportion of BA, NH_3 emission reduction would have been significant.

An improvement in growth performance promoted by BA dietary supplementation should be also expected, as found by other studies (Torrallardona *et al.,* 2005). This could be related to the increase of nutrient digestion (Sutton *et al.,* 1996; Mackie *et al.,* 1998). However, differences in BW, ADG and FCR in the first two experimental weeks did not reach significance, likely due to the low number of replicates used in the present study.

Combining all three dietary strategies did not have an additive effect, as predicted by several authors (Shriver *et al.,* 2002; Zervas & Zijlstra, 2002). By contrast, this treatment increases NH_3 emission relative to the LP diet and had the highest CH_4, N_2O and CO_2 emissions. In addition, the combination of three treatments adversely affected animal performance, and at day 7 BW was lower than piglets in SBP dietary tretament. All these negative results might be associated with a reduction of nutrient digestion, providing more substrate for bacterial fermentation in the hindgut and the consequent production of undesirable gases. However, more studies are required to assess possible negative interactions between all three dietary strategies applied at the same time.

In summary, under the experimental conditions of the present experiment we can conclude that the best dietary strategy studied to reduce NH_3 emission was the reduction of dietary CP content combined with AA supplementation, also promoting a CH_4 emission reduction. Dietary inclusion of NSP, such as SBP, was also efficient to decrease NH_3 emission, although other GHG emissions can be affected and increased by this strategy, particularly CH_4. The addition of 0.5% BA did not significantly affect NH_3 and GHG emissions. Animal performance was not affected by any of these dietary strategies, suggesting that the reduction of dietary CP content could be a good strategy in nursery piglets to reduce the environmental impact. On the other hand, combining these three strategies was not effective to reduce gas emissions and adversely affects animal performance.

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