Animal Nutrition 1 (2015) 24–29

Contents lists available at ScienceDirect

Animal Nutrition

journal homepage: http://www.keaipublishing.com/en/journals/aninu/

Original article

Dietary composition affects odour emissions from meat chickens

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ARTICLE INFO

Article history:
Received 18 November 2014
Accepted 3 February 2015
Available online 11 March 2015

Keywords:
Fourier transform infrared
Diet
Odour
Meat chicken

ABSTRACT

Abatement of odour emissions has become an important consideration to agricultural industries, including poultry production. The link between diet and odour emissions was studied in two experiments using Ross 308 male meat chickens reared in specially designed chambers in a climate controlled room. In the first experiment, two treatments were compared using three replicates of two birds per chamber. Two wheat-soy based treatment diets were formulated with or without canola seed, an ingredient rich in sulfur amino acids. Treatment 1 (T1) had 13.39 MJ/kg ME (as fed) and used 60 g/kg canola seed without corn while Treatment 2 (T2) contained 12.90 MJ/kg ME (as fed) and used 150 g/kg corn without canola seed. In the second experiment, birds were assigned to three dietary treatments of five replicates with five birds per replicate (chamber). The basal starter, grower and finisher diets in the control group (SBM group) contained soybean meal in the range of 227–291 g/kg (as fed) as the main protein source. The other treatments (CM and MBM groups) contained either high levels of canola meal (174–190 g/kg) or meat meal (74–110 g/kg) at the expense of soybean meal. In both experiments, diets were isocaloric, isonitrogenous and contained similar digestible amino acid contents as per 2007 Aviagen Ross 308 guidelines. Emissions of odour were measured using Fourier transform infrared (FTIR) spectroscopy. In both experiments, major odorous compounds detected included 2,3-butanedione (diacetyl), 2-butanone, dimethyl disulfide, methyl mercaptan, ethyl mercaptan, 2-butanol, 3-methyl-butanal, phenol and m-cresol. In the first experiment, T1 (with canola seed) produced higher concentration of methyl mercaptan ($P < 0.05$) and lower diacetyl ($P < 0.01$) than T2. In the second experiment, methyl mercaptan emission was higher in SBM group ($P = 0.01$) and total elemental sulfur were higher in SBM and CM groups up to day 24 ($P < 0.01$). Results of these experiments indicated a direct link between diet and odour emissions from meat chickens.

1. Introduction

Odours from poultry farms are a potential nuisance in the surrounding community. Odours generated from meat chicken houses are a result of both microbial decomposition of excreta in litter (Jiang and Sands, 2000) and emissions directly from the birds (Lacey et al., 2004). Recently, Murphy et al. (2014) reported eight major volatile organic compounds from tunnel ventilated meat chicken sheds that were considered important predictors of odour. These were dimethyl sulfide, dimethyl trisulfide (DMTS), 2,3-butanedione, 3-methyl-butanal, 1-butanol, 3-methyl-1-butanol, 3-hydroxy-2-butanone (acetoin), and 2-butanone. Previously, Jiang and Sands (2000), Dunlop et al. (2011) and Pillai (2011) reported similar odorous compounds plus mercaptans (methyl-, ethyl-, propyl-), dimethyl disulfide (DMDS), phenol, cresol, acetic, propionic and butanoic acids, indole and skatole as odorous compounds from meat chicken farms. In an effort to address odour issues from farms, there have been attempts to develop mitigation strategies including litter treatments, biofilters, neutralising agents, air scrubbers, ozone treatment, windbreak walls and short stacks but these techniques are generally costly or impractical due to the

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Peer review under responsibility of Chinese Association of Animal Science and Veterinary Medicine.

Production and Hosting by Elsevier on behalf of KeAi

http://dx.doi.org/10.1016/j.aninu.2015.02.003

required high ventilation rates in meat chicken farms (Dunlop et al., 2011). There is little information available linking diet composition to odour emissions to develop suitable odour mitigation strategies.

Diets can be formulated to more closely meet the bird's nutritional requirements to avoid overfeeding and to reduce excretion of undigested components. This will decrease the available substrates that the microbes metabolise to odour compounds (Mackie et al., 1998). The composition of meat chicken excreta is related to the composition of the diet. Chavez et al. (2004) reported the role of dietary methionine sources in generation of odorants from poultry excreta. They found hydrogen sulfide, carbonyl sulfide and DMDS emissions as measured by gas chromatography/mass spectrometry (GC/MS) to be higher in birds fed sodium methioninate as compared to birds fed D,L-methionine or liquid D,L-hydroxy-methyl-thio-butanoic acid or its dry calcium salt. Chang and Chen (2003) reported the benefits of adding lactobacillus containing probiotics to lower meat chicken house malodours. They found lower emission of 2-butanone, 1-butanol, DMDS and DMTS in diets supplemented with lactobacillus containing probiotics as measured by GC/MS. There is scant information available on the effects of different protein sources in meat chicken diets on odour emissions. In one study in growing-finishing pigs, van Heugten and van Kempen (2002) reported high manure odour concentration with the addition of feather meal up to 120 g/kg in the diets.

Soybean meal (SBM) is the most commonly used protein source in meat chicken diets worldwide and contains 460–480 g/kg CP and 8.37–10.47 MJ/kg ME (Ravindran et al., 2014). Canola meal (CM) contains approximately 340–370 g/kg CP and can be used as an alternative dietary protein source to SBM for meat chickens. However, diets formulated exclusively with plant protein sources increase water consumption and elevate litter moisture content (Vieira and Lima, 2005; Eichner et al., 2007; Hossain et al., 2013). In addition, because of the presence of many anti-nutritional factors in plant protein sources, high dietary levels of SBM or CM may produce wet litter. Litter moisture content is presumed to be one of the most critical factors affecting odour production in poultry sheds (Jiang and Sands, 2000; Carey et al., 2004). Meat and bone meal (MBM) is an animal by-product which is also used as a protein source in meat chicken diets at levels up to 120 g/kg. However, MBM varies widely in nutritional composition, contains a lower level of digestible protein and amino acids than soybean meal and has an unpleasant smell that could contribute to odour. Thus, it is of interest to study and compare litter odorants associated with diets varying in ingredients and nutrient contents.

Concentration of specific odorants can be quantified using real time gas analysers such as the Fourier transform infrared (FTIR) spectrometer. Van Kempen et al. (2002) and Witkowska (2013) successfully used FTIR to detect and quantify odours from swine and turkey houses, respectively. The objective of the current study was to use FTIR to examine odorant emissions from meat chickens fed diets differing in ingredients and nutrient composition.

2. Materials and methods

Two experiments were conducted to measure the effect of different diets on litter odorant emissions. In each experiment, randomly selected meat chickens were placed in specially designed chambers in a climate controlled room to measure odorants. The experiments were approved by the Animal Ethics Committee of the University of New England, Australia.

2.1. Metabolic chambers

The chambers that were used in this experiment were the same as the ones described by Swick et al. (2013). In short, 15 chambers made of stainless steel and equipped with a wire mesh cage were placed in a climate controlled room. Temperature and humidity in each chamber were monitored using the sensors and shown on an electronic display. The outlet in each chamber was connected to the FTIR for odour measurements.

2.2. Experimental design and diets

2.2.1. Experiment 1

A total of 288 day-old Ross 308 male meat chickens were reared in floor pens with wood shavings as a bedding material. The birds were fed a common starter diet to day 10, experimental grower diets from 10 to 25 days and experimental finisher diets thereafter. At the age of 22 days, 12 birds of uniform body weight were selected from a pool of 288 birds and adapted to the metabolic chambers for 6 days in a climate controlled room and fed their respective test diets. Litter materials were not used in this experiement and the birds were reared on raised wire floors. The experimental collection started when the birds were 28 days old and finished when they were 42 days old. Feed and water were provided *ad libitum*. Each diet was replicated three times with two birds per chamber. Two treatment diets were formulated according to the Ross 308 nutrient specifications for digestible amino acids (Aviagen, 2007). Diets were isonitrogenous but differed in ingredient composition and ME (Table 1).

2.2.2. Experiment 2

A total of 90 day-old Ross 308 male meat chickens were assigned to three dietary treatments with 30 chicks per pen reared for the first 10 days. Wood shavings were used as a bedding material. At the age of 10 days, 25 birds of uniform body weights were selected from each treatment and transferred to the metabolic chambers. Each treatment diet was replicated five times with five birds in each chamber. The litter accumulated during the first 10 days in the floor pens of respective treatments was collected in equal amounts (1.5 kg) and transferred to the chambers at the same time as the birds. Feed and water were provided *ad libitum* and intakes were recorded at day 24 and day 32. Basal diet (SBM group) contained only soybean meal as a protein source. The other two diets used CM and MBM at the expense of SBM. The CM diet had 60% of the protein source as canola meal and the MBM diet contained 43–54% of the protein source as MBM. Wheat was included in the diets at 600–700 g/kg and cottonseed oil and synthetic amino acids were added to make the diets isocaloric, isonitrogenous and to give them similar digestible amino acid contents. The diets were formulated according to the Ross 308 nutrient specifications for digestible amino acids (Aviagen, 2007) but with slightly lower ME than Ross 308 specifications. All diets contained xylanase and phytase enzymes (Table 2).

2.3. Gas collection and analysis

Gas concentrations were determined by FTIR using a portable multi-component Gasmet DX-4015 analyser (Gasmet Technologies, Finland). In experiment 1, gaseous samples were measured only once at day 42 in the presence of birds and excreta without litter material (birds on raised wire floor). In experiment 2, emissions were measured at day 24 and day 32 from birds, excreta and litter. Chamber lids were closed for approximately 15 min before sample collection. Water was used to seal the chambers. At that time there was zero air exchange and odorants were allowed to concentrate prior to sampling. Carbon dioxide (CO_2) and oxygen (O_2) levels inside chambers were recorded during the period of closure and remained at levels less than 2% (CO_2) and more than 18% (O_2), respectively. The FTIR was set up as follows: flushing time, 30 s; pumping time, 1 min; measuring time, 3 min. The gas samples were drawn at a flow rate of 2 L/min with the in-built pump in FTIR (i.e.

Table 1
Composition of the wheat-soy based experimental diets for experiment 1 (g/kg, as-fed basis).

Ingredients	Grower diet (10–25 days)		Finisher diet (26–42 days)	
	Wheat, canola seed (T1)	Wheat-corn no canola seed (T2)	Wheat, canola seed (T1)	Wheat-corn no canola seed (T2)
Wheat	668.4	591.1	723.6	638.9
Soybean meal	161.2	164.9	106.6	104.0
Meat and bone meal	76.3	77.3	75.2	76.9
Corn	0.0	134.0	0.0	150.0
Canola seed	60.0	0.0	60.0	0.0
Canola oil	18.0	16.2	20.0	14.6
Limestone	3.53	3.44	3.53	3.40
Xylanase powder[a]	0.05	0.05	0.05	0.05
Salt	0.48	0.37	0.47	0.36
Na bicarbonate	2.00	2.00	2.00	2.00
Vitamin mix[b]	0.50	0.50	0.50	0.50
Mineral mix[c]	0.75	0.75	0.75	0.75
Choline Cl, 70%	0.04	0.40	0.00	0.37
L-lysine HCl	3.44	3.47	3.15	3.93
D,L-methionine	2.97	3.04	2.22	2.32
L-threonine	1.80	1.80	1.41	1.44
Salinomycin[d]	0.50	0.50	0.50	0.50
Calculated nutrients				
ME, MJ/kg	13.2	12.7	13.4	12.9
CP	210	203	190	183
d Lys	11.0	10.6	9.55	9.76
d Met + Cys	8.40	8.10	7.30	7.04
d Thr	7.30	7.04	6.30	6.07
Ca	8.40	8.27	8.19	8.10
Av. P	4.20	4.13	4.10	4.05
Na	1.60	1.54	1.60	1.54
K	7.50	7.12	6.49	6.05
Cl	1.82	1.85	1.75	1.93
dEB[e], mEq/kg	210.1	197.0	186.3	167.3
Analysed DM	913.4	912.0	906.5	909.4

ME = metabolizable energy; CP = crude protein.
[a] Porzyme (Dupont Animal Nutrition).
[b] Vitamin concentrate supplied per kilogram of diet: retinol, 12,000 IU; cholecalciferol, 5000 IU; tocopheryl acetate, 75 mg, menadione, 3 mg; thiamine, 3 mg; riboflavin, 8 mg; niacin, 55 mg; pantothenate, 13 mg; pyridoxine, 5 mg; folate, 2 mg; cyanocobalamin, 16 μg; biotin, 200 μg; cereal-based carrier, 149 mg; mineral oil, 2.5 mg.
[c] Trace mineral concentrate supplied per kilogram of diet: Cu (sulfate), 16 mg; Fe (sulfate), 40 mg; I (iodide), 1.25 mg; Se (selenate), 0.3 mg; Mn (sulfate and oxide), 120 mg; Zn (sulfate and oxide), 100 mg; cereal-based carrier, 128 mg; mineral oil, 3.75 mg.
[d] Sacox (coccidiostat).
[e] Dietary electrolyte balance ($Na^+ + K^+ - Cl^-$).

2 L of gases were measured from each chamber) and the exhaust from the FTIR was fed back into the chamber. Before measurements, the analyser was zero calibrated using pure dry nitrogen gas. After the measurements, sample spectra were recorded and qualitative and quantitative analyses were conducted with the use of Calcmet Professional software with a library of reference spectra for 50 gases. Calcmet is Gasmet DX-4015 proprietary software and uses modified classical least square method for analysis of data. The concentrations of chemical compounds were expressed in ppm (v/v) units and total elemental sulfur from treatment groups is calculated as mg S/m^3. After finishing measurements from one treatment, FTIR was flushed with dry nitrogen gas for 15 min before taking measurements from the next treatment group.

2.4. Litter moisture and pH measurements

Five litter subsamples per chamber were sampled to obtain a representative complete litter profile (caked and friable). Pooled litter subsamples were then thoroughly mixed in a 1 L plastic box and moisture content and pH were assayed. Litter pH was determined by mixing litter and de-ionised water in the ratio of 1:5 and measuring with a pH meter (EcoScan 5/6 pH meter, Eutech Instrument Pte Ltd; Singapore).

2.5. Crude protein and dry matter measurements

The nitrogen content of each diet was determined by the Dumas combustion technique as described by Sweeney (1989) using a LECO FP-2000 automatic nitrogen analyser (Leco Corp., St. Joseph, MI, USA). Nitrogen content was multiplied by 6.25 to determine the CP content of the diets. Dry matter contents of diets and litter were determined by subjecting samples to forced air at 105 °C for 48 h.

2.6. Statistical analysis

The data were analysed by one-way analysis of variance using the general linear models procedure (SAS Institute Inc., Cary, NC). In experiment 1, differences among the treatment means were determined using the t-tests and in experiment 2, Duncan's multiple range test was used. Variability in the data is expressed as the standard error means and a probability level of $P < 0.05$ was considered to be statistically significant.

3. Results and discussion

3.1. Experiment 1

Altogether 24 volatile organic compounds were detected and quantified. Eight odorants suggested to be most likely to contribute to odour impacts are listed in Table 3. Methyl mercaptan (MM), DMDS, 2,3-butanedione, phenol and m-cresol were measured at higher concentrations than the odour detection threshold (Schiffman et al., 2001). MM has a rotten cabbage smell and was produced at higher levels ($P < 0.05$) from T1 group. DMDS was also detected in chamber air from both diets. DMDS is the oxidation product of MM. The results suggest that the use of 60 g/kg canola

Table 2
Composition of the treatment diets for experiment 2 (g/kg, as-fed basis).

Ingredients	Starter diet (0–10 days)			Grower diet (10–24 days)			Finisher diet (24–32 days)		
	SBM	MBM	CM	SBM	MBM	CM	SBM	MBM	CM
Wheat	627.2	760.3	600.0	670.5	757.7	604.6	704.8	777.6	646.2
Soybean meal	291.1	91.0	125.2	254.2	117.6	117.2	227.0	112.9	100.0
Meat and bone meal	–	110.0	–	–	90.0	–	–	73.9	–
Canola meal	–	–	180.0	–	–	190.0	–	–	174.1
Cottonseed oil	42.5	16.5	53.8	33.2	11.8	50.0	35.0	18.0	50.4
Limestone	12.88	–	11.75	12.4	–	11.10	12.07	3.41	10.90
Dicalcium phosphate	11.38	–	9.74	10.2	–	8.30	8.73	–	6.94
Xylanase[a]	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Phytase[b]	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Salt	2.59	0.66	2.31	2.92	1.37	2.65	2.92	1.65	2.68
Na bicarbonate	1.50	1.50	1.50	1.00	1.00	1.00	1.00	1.00	1.00
Titanium dioxide	–	–	–	5.00	5.00	5.00	–	–	–
Vitamin mix[c]	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Mineral mix[d]	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
Choline chloride	0.46	0.68	0.91	1.73	2.60	0.85	1.68	2.41	1.13
L-lysine HCl	3.48	6.46	5.15	2.70	4.41	3.37	1.77	3.24	2.43
D,L-methionine	3.23	3.87	2.78	2.80	3.19	2.05	2.14	2.48	1.47
L-threonine	1.84	3.02	2.27	1.50	2.19	1.51	0.97	1.56	1.00
L-tryptophan	–	0.11	–	–	–	–	–	–	–
L-isoleucine	–	1.17	0.61	–	0.40	0.03	–	–	–
L-arginine	–	2.08	1.77		0.68	0.57	–	–	–
L-valine	–	0.85	0.34	–	0.11	–	–	–	–
Calculated nutrients									
ME, MJ/kg	12.7	12.7	12.7	12.9	12.9	12.9	13.1	13.1	13.1
CP	223	224	216	200	205	202	190	192	190
d Lys	12.7	12.7	12.7	11.0	11.0	11.0	10.2	10.2	10.2
d Met + Cys	9.4	9.4	9.4	8.4	8.4	8.4	7.6	7.6	7.6
d Thr	8.3	8.3	8.3	7.3	7.3	7.3	6.5	6.5	6.5
Ca	9.5	10.5	9.5	9.0	9.0	9.0	8.5	9.0	8.5
Available phosphorous	4.8	6.5	4.8	4.5	5.8	4.5	4.2	5.2	4.2
Na	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8
K	9.2	6.0	7.8	8.6	6.4	7.8	8.2	6.3	7.4
Cl	2.8	2.8	2.9	3.0	3.0	2.8	2.8	2.8	2.6
dEB[e], mEq/kg	234.7	152.8	196.1	213.7	157.4	198.9	209.1	160.5	194.3
Analysed nutrients									
DM	904.8	901.1	902.6	911.4	913.1	916.6	901.0	901.3	906.1
CP	222.6	224.8	222.9	214.5	216.4	209.7	181.3	184.1	184.2

SBM = soybean meal; MBM = meat and bone meal; CM = canola meal; ME = metabolizable energy; DM = dry matter; CP = crude protein.
[a] Feedzyme XBC 1000G (Dupont Animal Nutrition).
[b] Phyzyme (Dupont Animal Nutrition).
[c] Vitamin concentrate supplied per kilogram of diet: retinol, 12,000 IU; cholecalciferol, 5000 IU; tocopheryl acetate, 75 mg, menadione, 3 mg; thiamine, 3 mg; riboflavin, 8 mg; niacin, 55 mg; pantothenate, 13 mg; pyridoxine, 5 mg; folate, 2 mg; cyanocobalamin, 16 μg; biotin, 200 μg; cereal-based carrier, 149 mg; mineral oil, 2.5 mg.
[d] Trace mineral concentrate supplied per kilogram of diet: Cu (sulfate), 16 mg; Fe (sulfate), 40 mg; I (iodide), 1.25 mg; Se (selenate), 0.3 mg; Mn (sulfate and oxide), 120 mg; Zn (sulfate and oxide), 100 mg; cereal-based carrier, 128 mg; mineral oil, 3.75 mg.
[e] Dietary electrolyte balance ($Na^+ + K^+ - Cl^-$).

seed in the diet led to higher levels of MM, a sulfur containing odorant in T1 compared to T2 that did not have canola seed. The calculated digestible methionine plus cysteine were similar in both diets (7.3 g/kg vs. 7.0 g/kg). This small difference in dietary sulfur amino acid level is unlikely to produce difference in sulfur odorants among treatments. However, a higher excreta moisture content was observed in birds fed T1 ($P < 0.05$). Increased litter moisture is associated with higher concentrations of organosulfides, aldehydes and alcohols (Murphy et al., 2014) due to increased anaerobic degradation (Jiang and Sands, 2000). Therefore, the higher organosulfide emission from T1 in this study was likely related to higher excreta moisture content.

Diacetyl (2,3-butanedione) has a rancid butter smell (Dunlop et al., 2011). This compound was produced at higher levels in T2 group ($P < 0.01$). Diacetyl is a product of fermentation and is considered an important odorant due to its low human detection

Table 3
Excreta moisture content and odorants emitted from meat chickens fed two commercial diets at 28–42 days in experiment 1 (in ppm, v/v).

Compounds	Wheat, canola seed (T1)	Wheat-corn no canola seed (T2)	SEM	*P*-value
2,3-Butanedione/diacetyl	1.099[b]	2.307[a]	0.286	0.005
2-Butanone	0.923	0.704	0.157	0.548
Dimethyl disulfide	3.242	3.079	0.154	0.651
Methyl mercaptan	19.393[a]	15.607[b]	0.940	0.014
2-Butanol	0.000	0.344	0.109	0.116
3-methyl-butanal	0.317	0.496	0.166	0.645
Phenol	0.880[b]	0.981[a]	0.026	0.027
m-cresol	0.582[b]	1.051[a]	0.112	0.006
Excreta moisture, %	76.20[a]	68.25[b]	1.530	0.035

SEM = standard error means.
[a,b]Means in the same row with different superscripts differ ($P < 0.05$) or ($P < 0.01$).

threshold (Murphy et al., 2014). The T2 group produced higher levels of phenol ($P < 0.05$) and m-cresol ($P < 0.01$). Phenol originates from the microbial degradation of tyrosine in the intestinal tract of animals and from phenolics contained in litter (Mackie et al., 1998; Le et al., 2005).

3.2. Experiment 2

3.2.1. Feed intake, water intake and litter characteristics

Feed intake (FI), water intake (WI), water:feed intake ratio (WI:FI), litter moisture and pH for treatment groups at various time intervals are presented in Table 4. At day 24, FI and WI were significantly higher in SBM and CM groups ($P < 0.01$) compared with MBM group. However, there was no significant difference in WI:FI between any treatments at day 24. From 24 to 32 days, FI was higher in the SBM group ($P < 0.01$) but the CM group consumed more water ($P < 0.05$) and had the highest WI:FI ($P < 0.01$). During the growing period (10–32 days), SBM and CM groups had higher WI ($P < 0.01$) than MBM group. The SBM group had the highest FI followed by the CM group ($P < 0.01$). However, the WI:FI was the highest in the CM group during the whole rearing period ($P < 0.05$).

There were no significant differences in pH or moisture contents of litter between SBM and CM groups but these were higher than that of the MBM group ($P < 0.05$). These findings were similar to that of Eichner et al. (2007) and Hossain et al. (2013) who also reported higher litter moisture with diets based exclusively on vegetable protein sources. Soybean meal has a higher K content than CM and MBM (Leeson and Summers, 2005) and this was reflected in the calculated dietary K content for SBM, MBM and CM diets, respectively (Table 2). As FI of the SBM and CM groups were also higher than the FI of the MBM group, the K intake further increased in these groups. Diets with increased Na and/or K result in increased WI (Smith et al., 2000) and litter moisture (Eichner et al., 2007). Because the Na contents of all the experimental diets were similar, it is likely that increased WI and litter moisture observed in the SBM group (and partly in CM group) were due to high K intakes. CM has higher sulfur content than SBM and MBM (Leeson and Summers, 2005). Thus, high dietary CM increases the total sulfur content in the diet. A high concentration of sulfur in the CM diet would have affected dietary electrolyte balance and contributed partly to wet litter. However, the commonly used dietary electrolyte balance equation ($Na^+ + K^+ - Cl^-$) doesn't take into account the sulfur content in the diet but the anion-cation ratio of the diet can be out of balance with an excess amount of sulfur if CM is included at high levels (Summers and Bedford, 1994).

CM contains a high crude fibre compared to SBM due to a much higher content of lignin and associated polyphenols (Khajali and Slominski, 2012). The FI of the CM group was lower than that of the SBM group for the entire experimental period but there was no difference in WI between these groups. Thus, WI:FI was higher in the CM group which suggests that birds that consume high CM diets drink more water per gram of feed ingested.

Table 5
Odorous compounds emitted from broilers at d 24 in experiment 2 (in ppm, v/v).

Compounds	Treatments			SEM	*P*-value
	SBM	MBM	CM		
Dimethyl disulfide	1.533	1.568	1.780	0.068	0.295
Ethyl mercaptan	1.430	1.725	1.765	0.078	0.160
Methyl mercaptan	6.673[a]	4.503[b]	5.303[b]	0.342	0.012
Total elemental sulfur, mg S/m^3	14.65[a]	12.28[b]	13.94[a]	0.274	0.005

SBM = soybean meal; MBM = meat and bone meal; CM = canola meal; SEM = standard error means.
[a,b] Means in the same row with different superscripts differ ($P < 0.05$) or ($P < 0.01$).

3.2.2. Odorants

The odorants measured at day 24 and day 32 are presented in Tables 5 and 6, respectively. More odorous compounds were detected at day 32 compared to day 24. Few more odorants were detected but occassionally at day 24 and thus not included. At day 24, MM emission was the highest in SBM group and the lowest in MBM group ($P = 0.01$) but total elemental sulfur were higher in SBM and CM groups ($P < 0.01$) compared with the MBM group. High FI and WI in SBM and CM groups could have produced more excreta with high moisture. High sulfur emissions may be due to a high moisture content and a lower pH (Dunlop, personal communication). Unfortunately, litter moisture and pH were not measured at day 24 in this study.

Nine odorants were detected consistently at day 32, but no significant difference in concentration was measured between treatments. This result explains the complex nature of odour. The total elemental sulfur were higher in groups fed SBM and CM diets at day 24 but were similar in birds fed the MBM diet at day 32. A lower litter pH in the MBM diet at day 32 was observed. While this treatment also had the lowest moisture content on day 32, differences in odorants were no longer significant as compared to measurements on day 24. A higher number and concentration of odorants was detected at day 32 suggesting that emissions would be more odorous at the later stage of growth. It is possible that the total excreta and moisture load toward the end of the growout may overwhelm any differences in odour production caused by diet.

Volatile fatty acids (VFAs) were detected from the emissions of all treatment groups. Acetic acid, propionic acid and butyric acids

Table 4
Water intake, feed intake and litter characteristics of meat chickens at various stages of growth (experiment 2).

Period	Parameters	Treatments			SEM	*P*-value
		SBM	MBM	CM		
10–24 days	FI, g	1271[a]	1088[b]	1191[a]	27.00	0.005
	WI, mL	2637[a]	2106[b]	2596[a]	83.71	0.002
	WI:FI	2.07	1.94	2.18	0.05	0.124
24–32 days	FI, g	812[a]	732[b]	754[b]	11.69	0.002
	WI, mL	1502[ab]	1294[b]	1663[a]	58.47	0.015
	WI:FI	1.85[b]	1.77[b]	2.21[a]	0.07	0.007
10–32 days	FI, g	2082[a]	1819[c]	1945[b]	35.51	0.0003
	WI, mL	4139[a]	3399[b]	4259[a]	125.66	0.0003
	WI:FI	1.99[b]	1.87[b]	2.19[a]	0.05	0.018
	Litter moisture, %	32.17[a]	19.36[b]	34.35[a]	2.43	0.006
	Litter pH	8.19[a]	6.76[b]	7.93[a]	0.24	0.010

SBM = soybean meal; MBM = meat and bone meal; CM = canola meal; SEM = standard error means; FI = feed intake; WI = water intake; WI:FI = water:feed intake ratio.
[a,b,c] Means in the same row with different superscripts differ ($P < 0.05$) or ($P < 0.01$).

Table 6
Odorous compounds emitted from broilers at day 32 in experiment 2 (in ppm, v/v).

Compounds	Treatments			SEM	SD	*P*-value
	SBM	MBM	CM			
2,3-Butanedione	0.418	0.178	0.293	0.068	0.236	0.392
Dimethyl disulfide	0.490	0.990	0.000	0.258	0.893	0.321
Ethyl mercaptan	1.310	1.545	1.378	0.105	0.364	0.685
Methyl mercaptan	5.553	4.793	6.705	0.404	1.401	0.301
Total elemental sulfur, mg S/m^3	10.29	10.91	10.60	0.273	0.947	0.792
2-Butanol	0.285	0.203	0.260	0.027	0.092	0.476
Phenol	0.490	0.600	0.535	0.022	0.076	0.110
Acetic acid	0.458	0.660	0.463	0.071	0.245	0.452
Propionic acid	0.300	0.430	0.255	0.069	0.240	0.608
Butyric acid	0.285	0.203	0.185	0.033	0.115	0.466

SBM = soybean meal; MBM = meat and bone meal; CM = canola meal; SEM = standard error means; SD = standard deviation.

are saccharolytic fermentation products, which are produced by anaerobic bacteria in the caeca of birds and in litter. It has been reported that an increase in the caecal or excreta VFA concentration will decrease manure pH and ammonia emissions (Canh et al., 1998). However, the effect of these VFAs on other odorous compounds and odour nuisance is inconsistent and not yet clear (Le et al., 2005). Some of the odorants were measured at higher concentrations in experiment 1 compared with experiment 2. The lower concentration of odorants measured in experiment 2 may be due to the presence of bedding materials (wood shavings) which may provide a surface for odorant adsorption or may reduce the diffusion of odorants from the litter. If this is the case, future research should focus on studying odour emissions from sheds while paying particular attention to the properties and conditions of the litter.

This study clearly showed that diet impacts odour emissions from meat chicken production. The use of closed circuit metabolic chambers coupled with FTIR allowed accurate detection and quantification of the odorous compounds, which are of interest to poultry industry. Minor changes in diet composition were found to change the relative abundance of gases associated with odours. Further investigation is warranted to more fully understand the effect of microbial metabolism of nutrients and metabolites in the gut and litter on odour formation.

Acknowledgements

This research was conducted within the Poultry CRC, established and supported under the Australian Government's Cooperative Research Centres Program (2.2.8). We would like to thank Mr Mark Dunlop (DAFF, Queensland Government, Australia) and Dr Isabelle Ruhnke (Research Fellow at UNE, Australia) for their valuable inputs.

References

Aviagen Inc. Ross broiler nutrition specification. 2007.
Canh TT, Sutton AL, Aarnink AJA, Verstegen MWA, Schrama JW, Bakker GCM. Dietary carbohydrates alter faecal composition and pH and ammonia emission from slurry of growing pigs. J Anim Sci 1998;76:1887–95.
Carey JB, Lacey RE, Mukhtar S. A review of literature concerning odours, ammonia, and dust from broiler production facilities: flock and house managemental factors. J Appl Poult Res 2004;13:509–13.
Chang MH, Chen TC. Reduction of broiler house malodour by direct feeding of a Lactobacilli containing probiotic. Int J Poult Sci 2003;2(5):313–7.
Chavez C, Coufal CD, Carey JB, Lacey RE, Beier RC, Zahn JA. The impact of supplemental dietary methionine sources on volatile compound concentrations in broiler excreta. Poult Sci 2004;83:901–10.
Dunlop M. Dust and odour emissions from meat chicken sheds. Final report. Australian Poultry CRC; 2011 Sep. Program: 3B. Project No.: 04–45.
Eichner G, Vieira SL, Torres CA, Coneglian JLB, Freitas DM, Oyarzabal OA. Litter moisture and foot pad dermatitis as affected by diets formulated on an all-vegetable basis or having the inclusion of poultry by- product. J Appl Poult Res 2007;16:344–50.
Hossain MA, Islam AF, Iji PA. Growth responses, excreta quality, nutrient digestibility, bone development and meat yield traits of broiler chickens fed vegetable or animal protein diets. S Afr J Anim Sci 2013;43:208–18.
Jiang JK, Sands JR. Odour and ammonia emission from broiler farms. Australia: A report for the Rural Industries Research and Development Corporation; 2000 Feb. RIRDC Publication N0.: 00/2, Project No.: UNS-11A.
Khajali F, Slominski BA. Factors that affect the nutritive value of canola meal for poultry. Poult Sci 2012;91:2564–75.
Lacey RE, Mukhtar S, Carey JB, Ullman JL. A review of literature concerning odours, ammonia and dust from broiler production facilities: odour concentrations and emissions. J Appl Poult Res 2004;13:500–8.
Le PD, Aarnink AJA, Ogink NWM, Becker PM, Verstegen WA. Odour from animal production facilities: its relationship to diet. Nutr Res Rev 2005;18:3–30.
Leeson S, Summers JD. Commercial poultry nutrition. 3rd ed. Canada: Context Products Ltd; 2005.
Mackie RI, Stroot PG, Varel VH. Biochemical identification and biological origin of key odour components in livestock waste. J Anim Sci 1998;76:1331–42.
Murphy KR, Parcsi G, Stuetz RM. Non-methane volatile organic compounds predict odour emitted from five tunnel ventilated broiler sheds. Chemosphere 2014;95:423–32.
Pillai S. Intercomparison of headspace sampling methods coupled to TD-GC-MS/O to characterise key odorants from broiler chicken litter. dissertation. Sydney: University of New South Wales; 2011.
Ravindran V, Abdollahi MR, Bootwalla SM. Nutrient analysis, metabolizable energy and digestible amino acids of soybean meals of different origins for broilers. Poult Sci 2014;93:2567–77.
SAS users guide. Cary, NC: SAS Institute; 2010.
Schiffman SS, Bennet JL, Raymer JH. Quantification of odours and odorants from swine operations in North Carolina. Agric For Meteorol 2001;108(3):213–40.
Smith A, Rose SP, Wells RG, Pirgozliev V. Effects of excess dietary sodium, potassium, calcium and phosphorus on excreta moisture of laying hens. Br Poult Sci 2000;41:598–607.
Summers JD, Bedford M. Canola meal and diet acid-base balance for broilers. Can J Anim Sci 1994;74:335–9.
Sweeney RA. Generic combustion method for determination of crude protein in feeds: collaborative study. J Assoc Off Anal Chem 1989;72:770–4.
Swick RA, Wu S, Zuo J, Rodgers N, Barekatain R, Choct M. Implications and development of a net energy system for broilers. Anim Prod Sci 2013;53:1231–7.
van Heugten E, van Kempen TA. Growth performance, carcass characteristics, nutrient digestibility and fecal odorous compounds in growing-finishing pigs fed diets containing hydrolyzed feather meal. J Anim Sci 2002;80:171–8.
van Kempen T, Powers W, Sutton A. Technical note: fourier transform infrared (FTIR) spectroscopy as an optical nose for predicting odour sensation. J Anim Sci 2002;80:1524–7.
Vieira SL, Lima IL. Live performance, water intake and excreta characteristics of broiler fed all vegetable diets based on corn and soybean meal. Int J Poult Sci 2005;4:365–8.
Witkowska D. Volatile gas concentrations in turkey houses estimated by fourier transform infrared spectroscopy. Br Poult Sci 2013;54(3):289–97.