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Kristin Hales

David B. Parker

N. Andy Cole

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Volatile organic compound flux from manure of cattle fed diets differing in grain processing method and co-product inclusion☆

Kristin Hales [a, *], David B. Parker [a, 1], N.Andy Cole [b]

[a] USDA-ARS, U.S. Meat Animal Research Center, P.O. Box 166, Clay Center, NE 68933, USA[2]
[b] USDA-ARS Conservation and Production Research Laboratory, P.O. Drawer 10, Bushland, TX 79012, USA

HIGHLIGHTS

- We collected urine and feces from cattle fed 4 different diets.
- We measured volatile organic compound (VOC) flux from feces and urine.
- We measured VOC flux from a combination of feces and urine based on animal output.
- VOC emission rates were higher from urine than feces.

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ABSTRACT

Odor emissions from livestock production have become increasingly important in the past decade. Odors derived from animal feeding operations are caused by odorous VOC emitted from the mixture of feces and urine, as well as feed and silage which may be experiencing microbial fermentation. Distillers grains are a by-product of corn grain fermentation used to produce fuel ethanol, and this industry has grown rapidly throughout the U.S. in past years. Therefore, the use of wet distillers grains with solubles (WDGS) in feedlot cattle diets has also increased. The objective of this research was to determine specific VOC emissions from feces and urine or a mixture of both, from cattle fed steam flaked or dry-rolled corn (DRC)-based diets containing either 0% or 30% WDGS. Flux of dimethyl trisulfide was greater from feces of cattle fed DRC than steam-flaked corn (SFC) diets. No other differences in flux from feces were detected across dietary treatments for phenol, 4-methylphenol, indole, skatole, dimethyl disulfide, and flux of volatile fatty acids (VFA) such as acetic, propionic, isobutyric, butyric, isovaleric, and valeric acids ($P > 0.15$). Flux of skatole, acetic acid, and valeric acid from urine was greater for cattle fed SFC than DRC diets ($P < 0.05$). Moreover, dimethyl disulfide flux was greater for cattle fed DRC vs. SFC diets ($P = 0.05$). When evaluating WDGS inclusion in the diet, flux of acetic acid and heptanoic acid from urine was greater when cattle were fed diets containing 0% WDGS than 30% WDGS ($P < 0.05$). When combining urine and feces in the ratio in which they were excreted from the animal, flux of propionic acid was greater when cattle were fed DRC vs. SFC diets ($P = 0.05$). Based on these results, the majority of the VOC, VFA, and odor flux from cattle feeding operations is from the urine. Therefore, dietary strategies to reduce odor from cattle feeding facilities should primarily focus on reducing excretion of odorous compounds in the urine.

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1. Introduction

Animal production has long been considered a source of odorous compounds. According to Mackie et al. (1998) the composition of manure is primarily undigested dietary components, endogenous secretions, bacterial cells, and related metabolic end products. Growth in the ethanol industry in the Southern Great Plains increased the use of wet distillers grains with solubles

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* Corresponding author.
E-mail addresses: Kristin.Hales@ars.usda.gov (K. Hales), Dparker@mail.wtamu.edu (D.B. Parker), Andy.Cole@ars.usda.gov (N.Andy Cole).
[1] Current address: West Texas A&M University, Palo Duro Research Center, Canyon, TX 79016, USA.
[2] USDA is an equal opportunity provider and employer.

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(WDGS) in beef cattle finishing diets (May et al., 2010) that was prevalent during the time the experiment was conducted.

Only 10%–20% of the nutrients consumed by livestock are retained (NRC, 1996) and cattle feedlots concentrate large quantities of manure in small areas. As a result of the ethanol fermentation process, protein, fat, fiber, phosphorus, and sulfur concentrations are generally 3× greater in WDGS than in corn that it replaces in feedlot diets (Klopfenstein et al., 2008). The presence of microbial populations in the manure lead to fermentation of undigested residues which produce volatile organic compounds (VOC; Mackie et al., 1998; Spiehs and Varel, 2009). Human odor perception is often linked to VOC found in livestock manure (Zahn et al., 2001). Aromatic compounds such as phenols and indoles are produced from proteins (Spoelstra, 1980), and volatile fatty acids (VFA) are produced from carbohydrate fermentation (Williams, 1984; Powers et al., 1999). Therefore, developing feeding strategies to decrease excretion of nutrients that affect odor production and flux from cattle feedlots could have profound environmental implications (Miller and Varel, 2001).

The specific objectives of the study were to: 1) determine specific VOC emissions from feces and urine separately, and when combined in a ratio based on daily output from cattle fed diets based on SFC or DRC with 0% or 30% WDGS.

2. Materials and methods

2.1. Live animal procedures

All procedures involving live animals were approved by and conducted within the guidelines of the Cooperative Research, Education, and Extension Team animal care and use committee (Texas Agrilife Research, USDA-ARS, West Texas A&M University). Four Jersey steers were used (initial body weight = 196 kg) and were housed at the USDA-ARS research laboratory near Bushland, TX. The Jersey breed was used because in general dairy breeds have a pleasant disposition and are more docile than beef breeds. The authors recognize that Jersey steers do not represent the feedlot industry, but the growth and development of Jersey cattle is similar to that of beef cattle. The experiment was conducted from May 2010 to August 2010. Steers were housed in four fly ash-surfaced pens (1 steer/pen; 3.7 m wide × 3.7 m deep). Steers had ad libitum access to fresh water and were fed above their maintenance requirement at all times (Hales et al., 2012a). The four treatments were as follows: 1) SFC-based diet with 0% WDGS (SFC-0); 2) SFC-based diet with 30% WDGS (SFC-30); 3) DRC-based diet with 0% WDGS (DRC-0); and 4) DRC-based diet with 30% WDGS (DRC-30). The control diets (SFC-0 and DRC-0) included added fat (yellow grease) and cottonseed meal to balance for fat and ruminally degradable protein. All diets were formulated to contain approximately 8.0% ruminally degradable protein and vitamins and minerals to meet or exceed animal requirements based on the NRC (1996) calculations. Each of the four periods in the Latin square consisted of an initial 16-d diet adaptation and 5 d of total fecal and urine collections with a total of 84 d for the experiment. More detailed animal procedures have been reported by Hales et al. (2012a).

During the collection periods, steers were housed in four chambers (1 steer per chamber). The flooring inside each chamber was made up of plastic boards, with a high density polyethylene pan (66 cm L × 51 cm W × 15 cm H) for urine collection placed underneath a plastic coated metal grate in the center of each chamber. An air-conditioning system (Fredrich Company, San Antonio, TX) was located inside each chamber to facilitate air circulation, remove humidity, and maintain the temperature within a thermoneutral range.

Urine was collected daily by vacuum aspiration from the polyethylene pan (150 mL of a 20% [vol/vol] HCl solution) to ensure the pH was <6 to prevent volatilization of ammonia and carbon dioxide from urea by the urease enzyme. Feces from each steer were collected in a nylon bag with a harness. Both urine and feces were weighed daily at 0830 on an analytical balance (1.0 g readability; Sartorius L2200, Data Weighing Systems Inc., Elk Grove, IL) and 10% aliquots were collected and stored at 4 °C until completion of the collection period. The daily urine and fecal aliquots from each steer were thoroughly mixed and composited into 1 sample per steer at the end of each collection period. Subsamples were then collected and frozen for shipment the U.S. Meat Animal Research Center, Clay Center, NE, where all sample analyses were performed. Freezing the manure samples would not likely alter the odorous compound flux (Miller and Woodbury, 2006).

2.2. Wind tunnel flux measurement

Samples were thawed overnight to 21 °C, and then sodium hydroxide was added to the urine samples to bring them back to the physiological pH of 8.0–9.0. Feces or urine (kept separate) and a mixture of the two were placed in a 138-mm diameter Petri dish such that the feces or urine were level with the top, and the dish was placed in the center of the wind tunnel. The wind tunnel had a Height of 51 mm, a Length of 305 mm, a Width of 152 mm, and a footprint of 4636 mm^2, and an internal volume of 2.36 L. Additional details on the wind tunnel construction are reported in Parker et al. (2013). Generally, the wind tunnel technique is a way to quantify emissions at a point in time; however, emission measurements over time are needed because odor and VOC flux from feces and urine are not static, and can have very active microbial populations which are constantly changing.

Sweep air was supplied from the laboratory compressed air system. The air was passed through an activated carbon filtration system to remove VOCs. Relative humidity was maintained at 10% by mixing dry and humidified air in a 15 L tank equipped with a PC-recorded relative humidity and temperature sensor (Model RH-USB, Omega Engineering, Stamford, CT, USA). The conditioned air was passed through a final rotameter to control the sweep air flow rate of 1 L min^{-1} into the wind tunnel.

Following an equilibration time allowing three volumes of sweep air to pass through the wind tunnel, VOC samples were collected from the air exiting the wind tunnel. Air samples were collected in stainless steel sorbent tubes filled with Tenax TA® sorbent using the same procedures described in Parker et al. (2013). Flux density was calculated on a mass per unit area per unit time basis (μg m^{-2} min^{-1}) as described in Parker et al. (2013).

2.3. Gas chromatography/mass spectrometry/statistical analyses

All sorbent tube samples were collected in duplicate and results were averaged. Sorbent tube samples were analyzed using the procedures outlined in Parker et al. (2013) using a thermal desorption-gas chromatography-mass spectrometry (TD-GC-MS) system. Samples were analyzed for eight volatile fatty acids (VFA: acetic, propionic, butyric, isobutyric, valeric, isovaleric, hexanoic, and heptanoic acid), four aromatic compounds (phenol, 4-methylphenol, indole, and skatole), and two sulfur-containing VOCs (dimethyl disulfide and dimethyl trisulfide). Calibration and method detection limit (MDL) calculations were conducted as previously described (Parker et al., 2013), and are presented in Table 1.

2.4. Dietary treatments

The dietary treatments are presented in Table 2. Wet distillers grains with solubles replaced either SFC or DRC, cottonseed meal, molasses, and urea. All diets included 10% alfalfa hay and 2.5% supplement. The diets with 0% WDGS (SFC-0 and DRC-0) contained more starch than the diets with 30% WDGS. Conversely, the 30% WDGS diets (SFC-30 and DRC-30) contained more protein, fat, and NDF than diets without WDGS.

All data were analyzed as a Latin square design using the Mixed procedure of SAS (SAS Inst. Inc., Cary, NC). The random effects of steer and period were included in the model, and the fixed effects of grain processing method, WDGS concentration, and the grain processing method × WDGS concentration interaction were evaluated by single degree-of-freedom *F*-tests. Effects were considered significant at *P*-value of ≤0.05, with tendencies declared at *P*-values between 0.05 and 0.10.

3. Results and discussion

3.1. Volatile organic compound flux

Flux of VOC from feces of cattle fed SFC-or DRC-based diets with 0% or 30% WDGS are presented in Table 3. There were no grain processing × WDGS inclusion interactions ($P > 0.21$); therefore, main-effect means were presented. It should be noted that even though the experiment was designed as a Latin square, only 4 animals were used and thus the results should be interpreted with regard to the small numbers of animals used. Only a few differences were noted in VOC flux when feeding SFC vs. DRC or 0% vs. 30% WDGS. There were no differences reported for flux of phenol, 4-methylphenol, indole, or skatole ($P > 0.24$) across grain processing methods or WDGS inclusions. Additionally, the values reported for indole and skatole were often below our minimum detection limits. In a study by Hales et al. (2012b) VOC flux was measured from feces and urine of cattle fed 0%, 15%, 30%, and 45% WDGS in a DRC-based diet, and no differences were reported in flux of phenol, indole, and skatole. Phenol and indole, are products of fermentation of the amino acids tyrosine and tryptophan, respectively (Mackie et al., 1998). Most 4-methylphenol excretion occurs in the urine of livestock rather than the feces (Mackie et al., 1998). Increases in fecal indole excretion of swine fed dried distillers grains have been reported (Hawe et al., 1992), which is plausible as tryptophan is 3-fold more concentrated in dried distillers grains than corn grain. Skatole is also a by-product of tryptophan metabolism (Mackie et al., 1998) by anaerobic intestinal bacteria.

No differences were observed in flux of dimethyl disulfide ($P > 0.32$) across grain processing method; however, flux of dimethyl trisulfide was greater in feces of cattle fed DRC vs. SFC ($P = 0.05$). Methionine and cystine are the primary sources of sulfide-containing compounds such as dimethyl disulfide and dimethyl trisulfide. To our knowledge, there should be no difference in the amino acid content of corn processed using different methods (dry-rolling or steam-flaking). The goal of grain processing in cattle feeding operations is to increase ruminal starch availability (Hales et al., 2010) which improves feed efficiency of the animal. Moreover, there were no differences in dimethyl disulfide or dimethyl trisulfide flux for cattle fed 0% or 30% WDGS ($P > 0.15$). These data are consistent with those reported by Hales et al.

Table 2
Composition and analyzed nutrient content (DM basis) of diets based on steam flaked (SFC) or dry-rolled corn (DRC) containing 0 or 30% wet distillers grains with solubles (WDGS).

Item	Treatment[a]			
	SFC-0	SFC-30	DRC-0	DRC-30
Ingredient, %				
Steam-flaked corn	73.00	56.00	–	–
Dry-rolled corn	–	–	73.00	56.00
WDGS	–	30.00	–	30.00
Alfalfa hay	10.00	10.00	10.00	10.00
Cottonseed meal	5.60	–	5.70	–
Yellow grease	3.50	0.85	3.50	0.91
Molasses	4.50	–	4.50	–
Urea	0.90	0.65	0.80	0.59
Supplement[b]	2.50	2.50	2.50	2.50
Analyzed composition[c], %				
DM	86.68	61.14	91.39	62.92
CP	13.24	17.36	13.12	17.27
Starch	48.63	39.58	53.09	43.00
NDF	11.48	16.39	14.63	18.80
Ether extract	6.52	6.83	6.00	6.49
Ash	5.23	5.38	7.89	7.31
Ca	0.98	0.89	0.90	0.83
P	0.31	0.45	0.29	0.43
S	0.15	0.33	0.15	0.33

[a] SFC-0, SFC-30 = SFC-based diet with 0 and 30% WDGS, respectively; and DRC-0, DRC-30 = DRC-based diet with 0 and 30% (DM basis) WDGS, respectively.
[b] Rumensin and Tylan (Elanco Animal Health, Greenfield, IN) and vitamins and minerals to meet or exceed NRC (1996) requirements were incorporated into a commercial supplement premix (Cargill Animal Nutrition, Amarillo, TX).
[c] Samples were analyzed by Servi-Tech Laboratories (Amarillo, TX).

Table 1
Summary of compounds quantified in the study, method detection limits, and calibration statistics for standard curves.

Compound	MW[a] (g/mol)	Retention time (min)	Min (ng)	Max (ng)	MDL[b] (ng)	MDL[b] (ug m^{-2} min^{-1})	RSD[c]	r^2
Phenol	94.1	20.2	5.5	1105	6.0	0.44	0.14	0.99
4-methylphenol	108.1	21.1	5.2	1045	4.0	0.29	0.11	0.99
Indole	117.1	25.2	6.3	1283	3.5	0.25	0.09	0.99
Skatole	131.2	25.6	7.1	1444	4.8	0.35	0.12	0.94
Dimethyl disulfide	94.2	5.2	5.3	2742	1.0	0.07	0.04	0.99
Dimethyl trisulfide	126.2	11.0	5.9	3084	2.1	0.16	0.14	0.99
Acetic acid	60.0	12.4	8.0	2210	16.3	1.18	0.38	0.99
Propionic acid	74.1	13.8	7.5	2083	7.5	0.54	0.89	0.99
Isobutyric acid	88.1	14.2	7.3	2020	6.8	0.49	0.82	0.99
Butyric acid	88.1	15.1	7.3	2020	4.1	0.29	0.87	0.99
Isovaleric acid	102.1	15.7	7.1	1957	2.8	0.20	0.80	0.99
Valeric acid	102.1	16.7	7.1	1957	1.2	0.09	0.62	0.99
Hexanoic acid	116.2	18.1	7.0	1936	0.54	0.04	0.50	0.99
Heptanoic acid	130.2	19.5	7.0	1936	0.77	0.06	0.25	0.98

[a] Molecular weight (MW).
[b] Method detection limit (MDL) for flux based on 4-min sampling time with wind tunnel flow rate of 1 L min^{-1}.
[c] Relative standard deviation (RSD) of the mean from 7 replications at minimum mass analyzed.

Table 3
Flux from feces of cattle fed steam-flaked–(SFC) or dry-rolled corn (DRC)-based diets with 0 or 30% wet distillers grains with solubles (WDGS).

Item	Grain processing method			WDGS, %			
	SFC	DRC	*P*-value[a]	0	30	*P*-value[a]	SE[b]
Phenol, μg m^{-2} min^{-1}	1.04	1.12	0.55	1.14	1.02	0.34	0.124
4-methylphenol, μg m^{-2} min^{-1}	1.77	2.19	0.42	1.92	2.05	0.80	0.403
Indole, μg m^{-2} min^{-1}	0.16	0.21	0.24	0.19	0.18	0.85	0.043
Skatole, μg m^{-2} min^{-1}	0.02	0.01	0.89	0.12	0.01	0.49	0.006
Dimethyl disulfide, μg m^{-2} min^{-1}	2.45	3.32	0.32	2.68	3.09	0.63	0.791
Dimethyl trisulfide, μg m^{-2} min^{-1}	0.27	0.41	0.05	0.29	0.39	0.15	0.080
Acetic acid, μg m^{-2} min^{-1}	57.38	53.06	0.84	47.46	62.99	0.46	14.140
Propionic acid, μg m^{-2} min^{-1}	60.35	50.26	0.77	36.80	73.81	0.31	23.535
Isobutyric acid, μg m^{-2} min^{-1}	47.07	26.36	0.52	20.93	52.50	0.34	22.206
Butyric acid, μg m^{-2} min^{-1}	4.60	3.36	0.62	2.91	5.05	0.39	1.670
Isovaleric acid, μg m^{-2} min^{-1}	2.43	1.63	0.60	1.29	2.78	0.35	1.043
Valeric acid, μg m^{-2} min^{-1}	8.66	2.64	0.36	2.48	8.82	0.34	4.912
Hexanoic acid, μg m^{-2} min^{-1}	4.79	2.29	0.40	2.10	4.98	0.34	2.323
Heptanoic acid, μg m^{-2} min^{-1}	0.43	0.30	0.45	0.25	0.48	0.20	0.150

[a] Observed significance level for grain processing method or WDGS concentration main-effect comparisons.
[b] Pooled standard error of main-effect means ($n = 4$).

(2012b) where no differences in dimethyl disulfide or dimethyl trisulfide flux were reported in the feces.

No differences were observed for flux of acetic, propionic, isobutyric, butyric, isovaleric, valeric, hexanoic, and heptanoic acid from the feces across grain processing and WDGS inclusion treatments ($P > 0.20$). This is somewhat unexpected, as volatile fatty acids generally comprise a large portion of the total VOC in cattle manure, yet acetic, propionic, and butyric have been reported to have a lower potential for odor than branched-chained and long-chained VFA (Spiehs and Varel, 2009; Hales et al., 2012a).

Spiehs and Varel (2009) and Varel et al. (2010) reported that total VFA concentration in feces was greater as more WDGS was included in the diet. Although not significant, the results of the current experiment would suggest that there is an increase in the flux of odorous compounds when increasing concentrations of WDGS are fed, as acetic, propionic, and isobutyric acid flux were all greater from feces of cattle fed 30% WDGS than cattle fed 0% WDGS (Table 3). In the current experiment, differences in flux of hexanoic and heptanoic acid were not detected across grain processing or WDGS inclusion treatments ($P > 0.20$). Typically the concentrations of these VOC are reported to be very low in cattle feces irrespective of the type of diet the cattle are fed (Hales et al., 2012a).

Flux from urine of cattle fed SFC- or DRC-based diets with 0% or 30% WDGS are presented in Table 4. There were no differences in phenol, 4-methylphenol, or indole flux when feeding SFC- or DRC-based diets with 0% and 30% WDGS ($P > 0.18$). The lack of difference observed in the flux of 4-methylphenol was a bit surprising because a majority of the phenols excreted by livestock species are present in the urine as 4-methylphenol (Mackie et al., 1998; Hales et al., 2012a) and diets containing WDGS have been reported to have an increase in urinary flux of 4-methylphenol (Hales et al., 2012b). It is common that as the protein concentration of the diet increases, urinary 4-methylphenol excretion also increases due to amino acid fermentation in the lower gut (Mackie et al., 1998; Hales et al., 2012a). In the current study the diets fed to the cattle were balanced for protein, which is probably the reason no differences in 4-methylphenol flux were noted. In the current study, skatole flux from urine tended to be greater in cattle fed SFC- than DRC-based diets ($P = 0.06$). The likely cause for the increase in skatole flux is unknown, but it could be related to the decrease in hind gut fermentation that occurs with feeding more extensively processed diets such as SFC which is digested more extensively in the rumen than DRC. Skatole is known to be produced by intestinal bacteria metabolizing tryptophan (Mackie et al., 1998), which could be

Table 4
Flux from urine of cattle fed steam-flaked–(SFC) or dry-rolled corn (DRC)-based diets with 0 or 30% wet distillers grains with solubles (WDGS).

Item	Grain processing method			WDGS, %			
	SFC	DRC	*P*-value[a]	0	30	*P*-value[a]	SE[b]
Phenol, μg m^{-2} min^{-1}	3.71	2.76	0.18	3.65	2.82	0.24	0.589
4-methylphenol, μg m^{-2} min^{-1}	14.65	6.38	0.27	13.26	7.77	0.45	5.200
Indole, μg m^{-2} min^{-1}	0.05	0.04	0.58	0.05	0.04	0.41	0.007
Skatole, μg m^{-2} min^{-1}	0.02	0.01	0.05	0.02	0.01	0.14	0.004
Dimethyl disulfide, μg m^{-2} min^{-1}	3.70	11.52	0.05	7.46	7.76	0.93	3.491
Dimethyl trisulfide, μg m^{-2} min^{-1}	0.31	0.58	0.28	0.48	0.41	0.78	0.173
Acetic acid, μg m^{-2} min^{-1}	36.23	23.31	0.03	35.70	23.84	0.04	3.755
Propionic acid, μg m^{-2} min^{-1}	5.55	3.82	0.17	5.52	3.85	0.18	1.006
Isobutyric acid, μg m^{-2} min^{-1}	1.23	0.85	0.29	1.06	1.02	0.92	0.335
Butyric acid, μg m^{-2} min^{-1}	3.52	2.39	0.33	3.41	2.50	0.43	0.937
Isovaleric acid, μg m^{-2} min^{-1}	0.66	0.31	0.20	0.45	0.52	0.76	0.219
Valeric acid, μg m^{-2} min^{-1}	1.11	0.61	0.05	1.06	0.66	0.11	0.232
Hexanoic acid, μg m^{-2} min^{-1}	3.05	1.54	0.22	3.43	1.16	0.08	0.867
Heptanoic acid, μg m^{-2} min^{-1}	0.40	0.25	0.14	0.43	0.22	0.05	0.077

[a] Observed significance level for grain processing method or WDGS concentration main-effect comparisons.
[b] Pooled standard error of main-effect means ($n = 4$).

Table 5
Flux from a mixture of feces and urine of cattle fed steam-flaked–(SFC) or dry-rolled corn (DRC)-based diets with 0 or 30% wet distillers grains with solubles (WDGS).

Item	Grain processing method			WDGS, %			
	SFC	DRC	*P*-value[a]	0	30	*P*-value[a]	SE[b]
Phenol, μg m^{-2} min^{-1}	3.17	4.08	0.16	3.85	3.40	0.45	0.533
4-methylphenol, μg m^{-2} min^{-1}	11.79	20.10	0.11	19.08	12.80	0.21	4.062
Indole, μg m^{-2} min^{-1}	0.98	0.74	0.26	0.74	0.98	0.26	0.175
Skatole, μg m^{-2} min^{-1}	0.15	0.04	0.22	0.03	0.16	0.16	0.061
Dimethyl disulfide, μg m^{-2} min^{-1}	2.20	1.80	0.62	2.22	1.79	0.59	0.682
Dimethyl trisulfide, μg m^{-2} min^{-1}	0.39	0.29	0.39	0.34	0.34	0.99	0.111
Acetic acid, μg m^{-2} min^{-1}	26.88	45.09	0.08	32.02	39.95	0.40	8.011
Propionic acid, μg m^{-2} min^{-1}	8.38	32.08	0.05	19.30	21.16	0.86	8.333
Isobutyric acid, μg m^{-2} min^{-1}	1.29	2.37	0.23	1.45	2.01	0.38	0.569
Butyric acid, μg m^{-2} min^{-1}	4.87	20.85	0.09	8.93	16.79	0.37	5.774
Isovaleric acid, μg m^{-2} min^{-1}	0.87	1.13	0.65	0.60	1.40	0.19	0.453
Valeric acid, μg m^{-2} min^{-1}	0.59	2.43	0.19	1.01	2.01	0.45	0.879
Hexanoic acid, μg m^{-2} min^{-1}	0.46	0.85	0.08	0.63	0.68	0.80	0.136
Heptanoic acid, μg m^{-2} min^{-1}	0.18	0.26	0.16	0.24	0.19	0.31	0.037

[a] Observed significance level for grain processing method or WDGS concentration main-effect comparisons.
[b] Pooled standard error of main-effect means ($n = 4$).

increased when feeding less ruminally digestible starch in the case of DRC. In addition, dimethyl disulfide flux from urine was greater ($P = 0.05$) in cattle fed DRC than SFC; however, there were no differences of flux from urine in cattle fed 0% vs. 30% WDGS ($P = 0.93$).

Acetic acid flux from urine was greater in cattle fed SFC- vs. DRC-based diets ($P = 0.03$), and greater in cattle fed 0% WDGS vs. 30% WDGS diets ($P = 0.04$). The reason for the increase in acetic acid flux is unclear. No differences from urine were detected in the flux of propionic, isobutyric, butyric, and isovaleric acid for cattle fed SFC- or DRC-based diets with 0% or 30% WDGS ($P > 0.17$). In contrast, valeric acid flux from urine was greater when cattle were fed SFC- vs. DRC-based diets ($P = 0.05$); and no differences were observed in valeric acid flux from cattle fed 0% or 30% WDGS diets ($P = 0.11$). Hexanoic and heptanoic acid flux from urine of cattle fed SFC vs. DRC was not different ($P > 0.14$). Conversely, hexanoic acid flux from urine tended to be greater in cattle fed 0% vs. 30% WDGS ($P = 0.08$) and heptanoic acid flux from urine was also greater in cattle fed 0% vs. 30% WDGS ($P = 0.05$).

To determine the flux of VOC to more closely simulate the feedlot pen surface, urine and feces were mixed in the ratio that they were excreted from the animal. The flux from the combination of the urine and feces is presented in Table 5. No differences in the flux from urine and feces combined were observed from cattle fed SFC- vs. DRC-based diets with 0% or 30% WDGS for flux of phenol, 4-methylphenol, indole, skatole, dimethyl disulfide, dimethyl trisulfide, propionic acid, isobutyric acid, isovaleric acid, valeric acid, and heptanoic acid ($P > 0.11$). A tendency for increased acetic acid flux was noted for cattle consuming DRC vs. SFC diets ($P = 0.08$); whereas, there were no differences in flux when cattle were fed 0% vs. 30% WDGS ($P = 0.40$). Similarly, there was also a tendency for increased butyric acid flux when cattle were fed DRC vs. SFC diets ($P = 0.09$), and no difference across WDGS inclusion ($P = 0.37$). Commonly, VFA such as acetic, propionic, and butyric acid are thought to be the primary odor causing agents in beef cattle manure (Spiehs and Varel, 2009). Hexanoic acid flux tended to be greater for cattle consuming DRC vs. SFC diets ($P = 0.08$).

4. Conclusions

As the fluxes of VOC and odorous compounds did not differ much in the current experiment, feeding strategies to focus on the reduction of total manure output from feedlot cattle would be beneficial in curtailing odor emissions.

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