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Exploratory observational quantification of liver abscess incidence, specific to region and cattle type, and their associations to viscera value and bacterial flora

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ABSTRACT

Objective: Our objective was to quantify incidence and economic effect of liver abscesses and identify predominant bacterial species specific to severity of abscesses, geographical region, and cattle type.

Materials and Methods: Observational liver audits occurred at 7 fed-beef (n = 130,845 livers) and 4 cull-beef (n = 30,646 livers) processing facilities. At each processing facility, intact liver abscess samples were collected and cultured for *Fusobacterium necrophorum*, *Trueperella pyogenes*, and *Salmonella enterica*. Outcome frequency and economic data were analyzed using generalized models with fixed effects of region, cattle type, or liver score.

Results and Discussion: Average liver abscess incidence was 20.3% for cattle slaughtered at fed-beef processing facilities and 17.6% for cattle slaughtered at cull-beef processing facilities. Within cattle type, fed Holsteins had greater ($P < 0.01$) abscess incidence rates (25.0%) than fed-beef steers (18.2%) or heifers (19.1%). Cull dairy cows, cull bulls, and cull range cows had total abscess incidence rates (19.8, 19.3, and 16.7%, respectively) similar to fed steers and heifers. *Fusobacterium necrophorum* ssp. *necrophorum* was present in 79.9% of samples collected from fed-beef processors and 76.9% of samples from cull-beef processors; *Salmonella enterica* was present in 27.5% of abscess samples collected from fed-beef processors and 16.5% of samples from cull-beef processors.

Implications and Applications: Total visceral losses ($/animal) did not differ by region ($P = 0.48$) or cattle type ($P = 0.86$), yet conservative estimates indicate that liver abscesses and other liver abnormalities cost the beef industry approximately $60 million annually in viscera losses.

Key words: bacterial flora, beef, Holstein, liver abscesses, viscera value

INTRODUCTION

Liver abscesses in fed beef have been observed and documented since Smith (1940) discussed incidence of liver abscesses and their contribution to reduced viscera yields. Of cattle slaughtered in 1940, 5.3% had liver abscesses; since then, reported incidence has more than tripled (17.8%; Eastwood et al., 2017). Liver abscess incidence of beef-type cattle by lot may range from 0% to upwards of 90% (Brown and Lawrence, 2010) but has averaged 15% in non-Holstein beef for the last decade, whereas in the same time period, fed Holsteins averaged 30% (Amachawadi and Nagaraja, 2016). Liver abscesses are typically polymicrobial infections that are believed to be ancillary to rumen acidosis (Nagaraja and Chengappa, 1998). Multiple species of bacteria have been cultured from liver abscesses, with the predominant flora being *Fusobacterium necrophorum*, *Trueperella pyogenes*, and *Salmonella enterica* (Lechtenberg et al., 1988; Nagaraja and Chengappa, 1998; Amachawadi and Nagaraja, 2016). However, no study has reported on the relationship of bacterial flora to severity of liver abscesses.

Regional differences in liver abscess incidence have been noted. Feedlot cattle slaughtered at processing facilities in Texas and Kansas were reported as having a 20.6% liver abscess incidence (Rezac et al., 2014b), whereas cull dairy cows slaughtered in the Great Lakes region had a 32.1% liver abscess incidence (Rezac et al., 2014a). Additionally,

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feedlot cattle in western Canada were reported as having a 30% incidence of A and A+ classified liver abscesses (Checkley et al., 2005). To better understand the liver abscess complex, a comprehensive audit was needed to better understand liver abscess incidence by geographical region and cattle type. Therefore, our objective was to quantify incidence and economic effects of liver abscesses and identify predominant bacterial species specific to severity of abscesses, geographical region, and cattle type.

MATERIALS AND METHODS

Animal care and use committee approval was not required for this study because data were recorded on carcasses. No live animals were used for sample and data collection.

Liver Audit

Observational liver audits occurred at 7 fed-beef and 4 cull-beef processing facilities. Processing facilities were selected to target the greatest frequency of Holsteins slaughtered per region. Each facility was audited for 1 wk of production during the period October 2015 through March 2016. Fed beef were audited in the following regions: Central Plains (n = 25,813), Desert Southwest (n = 10,119), High Plains (n = 27,034), Northeast (n = 7,958), North Plains (n = 50,671), and Pacific Northwest (n = 9,250). Cull beef were audited in the following regions: Great Lakes (n = 7,680), High Plains (n = 9,654), Northeast (n = 7,791), and West Coast (n = 5,521). For all regions, except for the North Plains (facilities = 2), only one processing facility by type (cull or fed) was audited. Names and locations of processing facilities were kept anonymous to ensure that liver abnormality and bacterial prevalence outcomes were not equated to an individual processor. It is important to note that although processors in this manuscript are denoted by primary type of cattle processed (fed or cull), fed-beef processors did process some cull-beef and cull-beef processors did process some fed-beef as part of their normal operations.

Within each processing facility, liver abscesses were visually assessed and scored according to a modified scoring system based on the Elanco Liver Check Service [✓ = no abscesses, A− = 1 or 2 small abscesses, A = 2 to 4 small active abscesses, A+ = multiple small abscesses or 1 or more large active abscesses, A+ Adhesion = liver adhered to gastrointestinal (**GI**) tract, and A+ Open = open liver abscess]. Other recorded liver abnormalities included cirrhosis, flukes, telangiectasis, carotenosis, sawdust, being torn, and whether a liver was condemned for contamination (adapted from Brown and Lawrence, 2010). Liver abscesses and other abnormalities were documented by individual carcass and matched with processor lot, sex, cattle type, and any additional information available. Liver abscess and other abnormalities are reported by processing facility (fed beef or cull beef) and by cattle type. Within each processing facility, various cattle types were processed; therefore, data were reorganized to clarify incidence of liver abscesses and other abnormalities regardless of region or processing facility.

Visceral Loss

Visceral loss was estimated from the USDA Agricultural Marketing Service by-product drop value (steer) report (USDA, 2016a, Friday report of every week) and weekly USDA by-product drop value (cow) report (USDA, 2016b). Value of lost viscera was estimated using the unrealized revenue from condemned liver or condemned liver and gut mass (hearts, reg, bone out; tripe, scalded edible, bleached; tripe, honeycomb bleached; lungs, inedible; melts) when open abscesses occurred. Using those reports, the average edible fed-beef liver was valued at \$6.44, and every edible cull-beef liver was valued at \$2.23. Similarly, an edible fed-beef GI mass was valued at \$14.84, and an edible cull-beef GI mass was valued at \$16.14. When a liver or GI mass is condemned by the USDA, the product goes to rendering and is salvaged as inedible meat and bone meal. Regardless of whether the GI mass is passed or condemned by USDA inspectors, fat deposits from around the viscera are salvaged as inedible tallow. These values were not included in viscera loss calculations because tallow is salvaged regardless of condemnation.

Meat and bone meal salvage values were estimated using the same reports (NW_LS441, NW_LS444) and time period (October 2015 through March 2016). A rendered fed-beef liver was valued at \$0.39, whereas a rendered liver from cull beef was valued at \$0.28. Value of rendered GI mass was estimated to be \$0.72 for fed beef and \$0.83 for cull beef. To estimate lost value per animal, the value of rendered product was subtracted from the value of edible product to establish a non-region-specific baseline loss for fed-beef viscera and cull-beef viscera. Once adjusted, liver values were then multiplied by total abscessed liver rate, total contamination rate, and total other abnormality rate for each cull- and fed-beef processor. Also, GI mass value was multiplied by the open abscess rate, because GI mass is condemned when an open abscess is present. Values were summed to quantify total liver and GI mass value [i.e., \$6.05 × liver loss (abscess + contamination + other) + \$14.12 × open abscesses]. Then total, value was divided by the total number of animals evaluated per processing facility to generate viscera losses per animal, by region and type.

Once viscera loss per animal was generated, by region and type, calculations were scaled to a national level. National slaughter numbers were generated using the USDA estimated daily Livestock Slaughter under Federal Inspection report (SJ_LS710; USDA, 2017). Estimated daily livestock slaughter was approximately 113,000 animals per day, 80% (90,400) of that number was fed beef and 20% (22,600) was cull beef. Using a 5.5-d work week, 286 slaughter days in the United States were estimated, resulting in approximately 25,854,400 fed beef and 6,463,600 cull beef slaughtered per year. Data are reported in dollars per animal.

Bacterial Sampling and Analysis

At each processing facility, 30 (10 A−, 10 A, 10 A+) intact liver abscess samples were collected. Due to laboratory schedules and sampling constraints presented by processors, samples were not collected on the same day and were not able to be collected in a matter that would balance cattle type by region. Therefore, samples were collected on a first-come, first-sampled basis at the processing facility; consequently, only region-specific differences in bacterial prevalence were statistically analyzed. Intact liver abscesses were excised from the liver to preserve the anaerobic environment inside the abscess. Samples were individually identified in plastic bags, placed in coolers packed with ice, and shipped overnight to Kansas State University to determine incidence of *F. necrophorum*, *T. pyogenes*, and *S. enterica*. The procedures described by Amachawadi et al. (2017) were used for isolation and identification of the 3 bacterial species.

The abscess was opened by searing the surface of the abscess with a hot spatula and incising the capsule with a sterile scalpel. Once opened, the inside wall of the abscess was swabbed and streaked onto 3 plates of blood agar (Remel) and, with a different swab, 2 plates of Hektoen-Enteric (**HE**) agar (Beckton and Dickson; for isolation of *Salmonella*). One blood agar plate and one HE plate were incubated anaerobically inside an Anaerobic Glove Box (Thermo Fisher Scientific Inc.), and another set of blood agar and HE plates were incubated aerobically. The blood agar plate for *T. pyogenes* isolation was incubated in a 5% CO_2 incubator. In addition to direct plating on HE plates, samples for *Salmonella* determination were also subjected to an enrichment step, first in tetrathionate broth (Beckton and Dickson; at 37°C for 24 h) and then in Rappaport-Vassiliadis broth (Beckton and Dickson; at 37°C for 24 h), before plating onto HE agar and incubated at 37°C for 24 h. Colonies presumed to be *Salmonella* were tested by agglutination with *Salmonella* polyvalent O antiserum (Beckton and Dickson) for genus confirmation. If positive, the colony was then subjected to B, C1, C2, D1, D2, and E antisera for serogroup identification.

Presumptive *F. necrophorum* colonies were cultured in brain heart infusion broth that had been pre-reduced with 0.05% cysteine HCl and anaerobically sterilized (BHI-S). Purity of possible *F. necrophorum* isolates was verified, microscopic morphology was determined, and species confirmation was with the RapId-ANA II test kit (Thermo Fisher Scientific Inc.). *Fusobacterium necrophorum* isolates were subspeciated (*necrophorum* or *funduliforme*) based on sedimentation characteristics in BHI-S broth and phosphate test as described by Tan et al. (1994). Likely *T. pyogenes* colonies, identified as pin-point colonies with a narrow encompassing zone of β hemolysis, were inoculated into tryptic soy broth (Beckton Dickson) and replated on blood agar plates to confirm purity of the isolate. The species confirmation of *Salmonella* and *T. pyogenes* was by matrix-assisted laser desorption/ionization time-of-flight (MALDI-TOF; Bruker Daltonics Inc.) mass spectrometry (Veterinary Diagnostic Laboratory, Kansas State University).

Statistical Analysis

This experiment was a nonrandomized observational study with carcass or liver as the experimental unit. Outcome frequency and economic data were analyzed using the GENMOD procedure of SAS v9.4 (SAS Institute Inc.), with the fixed effects of region, cattle type, or liver score. Least squares means were generated and separated using the PDIFF option with a Tukey-Kramer adjustment for multiple comparisons. Significance was declared at $P \leq 0.05$.

RESULTS AND DISCUSSION

Liver Abscess and Other Abnormality Incidence by Region and Cattle Type

Average liver abscess incidence was 20.3% (Table 1) for cattle slaughtered at fed-beef processing facilities, which is consistent with the 2016 National Beef Quality Audit report (Eastwood et al., 2017). Within fed-beef processing facilities, High Plains and Northeast regions had the greatest ($P < 0.01$) edible liver incidence rates (76.9 and 72.9%, respectively), whereas the Pacific Northwest region had the lowest edible liver incidence rate (46.8%). Furthermore, the greatest ($P < 0.01$) total abscess incidence rate for a fed-beef processor occurred in the Pacific Northwest (33.8%), whereas the Northeast region had the fewest liver abscesses (10.0%). Cattle finished in the Northeast are more likely to be fed a silage-based ration (Asem-Hiablie et al., 2018), which may have contributed to reduced abscess incidence rates in comparison with those fed a "traditional" midwestern (Asem-Hiablie et al., 2016) or western (Asem-Hiablie et al., 2017) feedlot diet that is not likely silage based. Increasing silage inclusion results in dilution of energy density (Burken et al., 2017). Furthermore, silage has a larger particle size than most concentrate feeds, and larger particle size promotes increased feeding durations and decreased rate of intake (Allen, 1996; Addah et al., 2016). Both of these factors lead to a slower rate of fermentation and a potential decrease in the incidence of acidosis.

Grain type has affected incidence of liver abscesses (Hale, 1985), and in the US Pacific Northwest and Western Canada regions, wheat and barley are commonly produced and incorporated into feedlot rations (Nelson et al., 2000; Beauchemin and Koenig, 2005). These grains are rapidly fermented in the rumen, which allows for greater variations in ruminal pH and the subsequent development of acidosis, ruminitis, and liver abscesses (Nagaraja and

Table 1. Liver abscess incidence and estimated processor visceral loss per animal by region

		Liver score, %										
Region	**n**	**Edible**	**Total abscess**[2]	**A−**	**A**	**A+**	**A+ Adhesion**	**A+ Open**	**A+ Adhesion/Open**	**Contamination**	**Other abnormality**[3]	**Viscera loss,[1] $/animal**
Fed-beef processors	130,845	69.2	20.3	8.2	2.5	2.9	5.0	1.2	0.5	7.5	3.0	2.11
Central Plains	25,813	70.0[bc]	25.5[b]	10.5[ab]	2.9	3.6	7.7[abc]	0.4	0.4	3.4[d]	1.1[f]	1.93
Desert Southwest	10,119	66.8[cd]	24.3[b]	7.9[bc]	3.0	2.5	8.4[abc]	1.7	0.9	7.6[bcd]	1.3[f]	2.38
High Plains	27,034	76.9[a]	15.5[d]	6.0[bcd]	1.8	2.1	4.7[bcd]	0.6	0.2	5.6[cd]	2.0[ef]	1.51
Northeast	7,958	72.9[ab]	10.0[e]	4.1[cd]	1.7	1.6	1.7[d]	0.7	0.2	11.2[ab]	5.9[cde]	1.80
North Plains–A	26,485	71.8[b]	16.0[d]	6.8[bcd]	2.5	2.1	4.0[cd]	0.4	0.3	8.6[bc]	3.6[def]	1.80
North Plains–B	24,186	65.1[d]	21.4[bc]	8.9[b]	3.4	4.4	1.9[d]	2.3	0.5	10.8[b]	2.7[ef]	2.51
Pacific Northwest	9,250	46.8[f]	33.8[a]	14.0[a]	1.7	2.6	8.5[abc]	4.6	2.3	9.2[bc]	10.2[abc]	4.20
Cull-beef processors	30,646	63.0	17.6	5.0	1.9	1.9	7.1	1.1	0.6	10.0	9.4	0.97
High Plains	9,654	56.7[e]	22.6[b]	6.3[bcd]	2.3	3.2	8.7[ab]	1.5	0.6	8.1[bc]	12.5[ab]	1.17
Great Lakes	7,680	76.4[a]	14.9[d]	6.6[bcd]	1.2	1.3	4.1[cd]	1.3	0.4	5.9[cd]	2.8[ef]	0.72
Northeast	7,791	57.8[e]	13.7[de]	3.7[cd]	2.3	1.5	5.6[bcd]	0.4	0.2	15.5[a]	13.0[a]	0.92
West Coast	5,521	63.0[d]	17.8[cd]	2.3[d]	1.6	1.1	10.7a	0.9	1.2	11.2[ab]	8.0[bcd]	1.05
P-value		<0.01	<0.01	<0.01	0.92	0.37	<0.01	0.11	0.94	<0.01	<0.01	0.48

[a–f]Means within a column lacking common superscripts differ ($P < 0.05$).

[1]Viscera loss includes unrealized revenue from condemnation of liver and gut mass (presence of open abscess).

[2]Total abscess is a sum of A−, A, A+, A+ Adhesion, A+ Open, and A+ Adhesion/Open.

[3]Other abnormality includes cirrhosis, flukes, telangiectasis, carotenosis, sawdust, and being torn.

Chengappa, 1998). Cattle in this region are more likely to encounter diets containing these ingredients, which may explain the increased liver abscess incidence observed at the processor in the Pacific Northwest region. Cattle from the Pacific Northwest region also had the greatest ($P < 0.01$) incidence of other abnormalities compared with the remaining fed-beef facilities (10.2 vs. 2.8%, respectively), primarily due to increased incidence of liver flukes, which contributed to the decreased rate of edible livers. The lifecycle of a liver fluke is dependent on its snail transitional host; therefore, the distribution of the parasite is limited to geographical areas (Gulf Coast and Pacific Northwest) where annual rainfall is high and pastures are poorly drained (Kaplan, 2001).

Average liver abscess incidence was 17.6% for cull-beef processing facilities (Table 1). Within cull-beef processing facilities, cattle from the Great Lakes region had the greatest ($P < 0.01$) incidence of edible livers (76.4%), whereas cattle from the High Plains and Northeast regions had the lowest edible liver incidence rate (56.7 and 57.8%, respectively). Cull animals from the High Plains region had the greatest ($P < 0.01$) total abscess incidence rate (22.6%), whereas the Northeast region had the fewest total abscesses (13.7%). It is possible that dairy herd size may have affected observed liver abscess incidence by region, because 63.7% of the carcasses observed in the High Plains cull-beef processor were of dairy influence. The High Plains region is becoming a major dairy-producing region, where milk production increased by 6.2 billion pounds (2.8 billion kg) from 1994 to 2006, and the average herd size in the region is greater than 500 head (MacDonald et al., 2007). In the same time period, milk production in the Great Lakes remained steady, and the average herd size in the region remained less than 100 head (MacDonald et al., 2007). When Hadley et al. (2006) analyzed dairy culling trends by herd size and region, they reported that the primary reason cattle were culled from small herds (<300 head) was injury; although injury remains the principal culling factor in larger herds, additional culling factors (i.e., disease, mastitis, low production) increased as herd size increased. Although data are lacking in literature, Doré et al. (2007) suggested that liver abscesses could affect milk production. Due to the immune system challenge brought about when fighting an active infection and concomitant decreased metabolic efficiency of the liver, culling for decreased milk production could be an outcome of liver abscesses.

When data were segregated by cattle type (Table 2), Holsteins had greater ($P < 0.01$) abscess incidence rates (25.0%) than fed-beef steers (18.2%) or heifers (19.1%). Reasons for greater liver abscess incidence in Holsteins are not known, but the predominant theory is based on increased days on a high-energy diet (Amachawadi and Nagaraja, 2016). Holsteins are on feed for longer periods of time than conventional fed-beef animals (300 to 400 d on feed for Holsteins vs. 120 to 150 d on feed in non-Holstein beef; Vogel and Parrott, 1994; Duff and McMurphy, 2007). Additionally, Holstein steers have a greater daily DMI (on average, up to 12% greater) than beef breeds at similar weights (Hicks et al., 1990), which is attributed to an increased maintenance energy demand due to a greater proportion of GI and organ tissue. Furthermore, increased DMI increases the fermentable substrate in the rumen, allowing for prolonged ruminal fermentation and greater decreases in rumen pH (Owens et al., 1998).

It is also likely that management of Holstein calves might affect rumen health and total abscess incidence. Holstein calves are commonly removed from their dams immediately after birth and are bottle fed as they are transitioned to concentrate diets, with some calves being completely weaned by 4 wk of age (Franklin et al., 2003). Although introduction of easily fermentable carbohydrates along with early ruminal muscular development due to GI fill allow for early weaning and ruminal development of Holstein calves, few precautions are taken to mitigate the development of acidosis in calves (Kristensen et al., 2007). Calves that ingested corn-based starter diets had subsequent decreased ruminal pH, with measurements nearing a pH of 5.5 (Anderson et al., 1987), which has been considered by some to be at risk for subacute acidosis (Nordlund et al., 2004).

Generally, chronic acidosis is considered when ruminal pH decreases to 5.6, whereas acute acidosis is achieved when ruminal pH is below 5.2 (Owens et al., 1998). Calves with measured ruminal pH near 5.5 are not nearing acute acidotic conditions, but the amount of time subjected to suboptimal ruminal pH may have unknown long-term effects. However, what is still unknown is how long a rumen must be subjected to suboptimal pH before detrimental damage is inflicted upon the rumen microbial community, resulting in subsequent decreases in digestion and rumen function (Nagaraja and Titgemeyer, 2007). Like feedlot cattle, calves may experience acidosis, and damage to the epithelial lining of the rumen may promote the development of rumen wall abscesses (Nagaraja and Chengappa, 1998). Feedlot cattle undergo these conditions at an older age, whereas Holstein calves undergo them early in life, because they spend less time on milk and are transitioned to an energy intensive diet before most non-Holstein beef. The increased potential for acidotic events throughout the life of a fed Holstein may further contribute to the increased incidence of liver abscesses.

Cull beef had abscess incidence rates (18.8%) similar ($P = 0.99$) to fed beef (20.0%; Table 2). Cull dairy cows and cull bulls exhibited total abscess incidence rates (19.8 and 19.3%, respectively) similar ($P > 0.10$) to fed steers and heifers (18.2 and 19.1%, respectively). Because the conditions animals were subjected to before slaughter were unknown, it is possible that some cull beef could have been fed a high-energy diet before slaughter, however unlikely, especially for cull bulls. Cull range cows had an abscess incidence rate (16.7%) similar ($P = 0.40$) to cull dairy cows (19.8%), which was unexpected because cull range cows are not fed diets similar to dairy cows or fed-beef animals,

Table 2. Liver abscess incidence and estimated processor visceral loss per animal by cattle type

Type	n	Liver score, %										Viscera loss,[1] $/animal
		Edible	Total abscess[2]	A−	A	A+	A+ Adhesion	A+ Open	A+ Adhesion/Open	Contamination	Other abnormality[3]	
Fed beef	132,796	70.1	20.0	8.1	2.5	2.9	4.8	1.2	0.5	7.1	2.7	2.05
Steer	64,449	72.5^{a}	18.2^{bc}	7.7^{ab}	2.4	2.7	4.0^{cd}	1.0	0.4	6.8^{b}	2.5^{c}	1.85
Heifer	33,240	70.3^{ab}	19.1^{bc}	8.2^{a}	2.6	2.9	3.7^{d}	1.3	0.4	7.2^{b}	3.4^{c}	2.04
Holstein[4]	26,169	65.0^{cd}	25.0^{a}	8.7^{a}	2.4	3.0	8.1^{abc}	1.8	1.0	7.9^{b}	2.1^{c}	2.52
Mixed lot[5]	8,938	67.3^{bc}	21.7^{ab}	8.8^{a}	2.9	3.1	5.3^{bcd}	1.0	0.6	7.0^{b}	4.0^{c}	2.20
Cull beef	28,695	58.1	18.8	5.2	2.0	1.9	8.1	0.7	0.8	11.8	11.3	1.05
Bull	984	61.5^{de}	19.3^{bc}	3.9^{b}	2.0	2.1	10.4^{a}	0.3	0.6	10.2^{ab}	9.0^{b}	0.89
Dairy cow	18,306	57.6^{e}	19.8^{bc}	5.1^{ab}	2.0	1.7	9.3^{ab}	1.0	0.7	12.4^{a}	10.1^{ab}	1.09
Range cow	9,405	58.8^{e}	16.7^{c}	5.7^{ab}	2.1	2.3	5.5^{bcd}	0.3	1.0	10.8^{ab}	13.7^{a}	1.00
P-value		<0.01	<0.01	<0.01	0.99	0.95	<0.01	0.94	0.99	<0.01	<0.01	0.86

[a–e]Means within a column lacking common superscripts differ ($P < 0.05$).

[1]Viscera loss includes unrealized revenue from condemnation of liver and gut mass (presence of open abscess).

[2]Total abscess is a sum of A−, A, A+, A+ Adhesion, A+ Open, and A+ Adhesion/Open.

[3]Other abnormality includes cirrhosis, flukes, telangiectasis, carotenosis, sawdust, and being torn.

[4]Holstein includes Holstein steers (n = 23,364), Holstein heifers (n = 1,294), and mixed Holsteins (n = 1,511).

[5]Mixed lot includes steers and heifers.

unless fed before slaughter. National Non-Fed Beef Quality Audits have reported liver condemnation rates in cull beef of 30.8% (1994) and 24.1% (1999), with 27.3% of liver condemnations in the 1999 audit being from liver abscesses (e.g., 6.6% liver abscess incidence; Roeber et al., 2001). The 2016 National Beef Quality Audit reported 20% liver abscess incidence in market cows/bulls (Eastwood et al., 2018), whereas another survey reported 32% incidence of liver abscesses in cull beef; however, 87% of that population were Holstein cows (Rezac et al., 2014a).

Although changes in weather patterns, forage availability, and feedstuff management by producers can influence liver abscess development in all segments of cattle production, it is possible that cull range cows develop liver abscesses from *F. necrophorum* entering portal circulation via routes other than through rumen wall abscesses caused by acidotic events. *Fusobacterium necrophorum* is able to survive in the soil of pastures and has been isolated from the oral cavity, GI tract, and genitourinary tract of normal, healthy animals (Langworth, 1977). Furthermore, it has been reported that liver abscesses may be formed as a result of traumatic reticuloperitonitis ("hardware disease"; Nagaraja and Smith, 2000). Because *F. necrophorum* is ubiquitous to the GI tract of ruminants, perforations in the epithelial lining of the GI tract may provide a route for this bacterium to enter portal circulation. Of cattle observed during the 2016 National Beef Quality Audit, cull beef (Harris et al., 2018) were 3-fold more likely to have tongues trimmed for hair sores and 14-fold more likely to have tongues trimmed for cactus tongue than fed beef (Eastwood et al., 2017). In addition, cull beef were 3-fold more likely to have tongues condemned at slaughter than fed beef (Eastwood et al., 2017; Harris et al., 2018). These data suggest that cull beef may be more likely to experience trauma to the lining of the mouth or esophagus, which could explain why cattle not fed a concentrate-based ration have liver abscess incidences similar to feedlot and dairy cattle.

Bacterial Incidence by Region and Liver Score

Fusobacterium necrophorum ssp. *necrophorum* was present in 79.9% of abscesses from fed-beef processing facilities and 76.9% of abscesses from cull-beef plants (Table 3). These data are consistent with incidence rates reported by Nagaraja and Chengappa (1998). Fed-beef processing facilities in the Central Plains and High Plains regions had the greatest ($P < 0.05$) incidence of *F. necrophorum* ssp. *necrophorum* (88.0 and 88.5%, respectively) in liver abscesses when compared with other geographic regions. *Fusobacterium necrophorum* ssp. *funduliforme* was isolated from 24.3% of abscess samples taken from fed-beef processors and 17.6% of abscess samples collected at cull-beef facilities. Liver abscesses cultured from the Pacific Northwest region had the greatest ($P < 0.05$) incidence (44.0%) of *F. necrophorum* ssp. *funduliforme*, whereas abscesses cultured from cull-beef processors in the High Plains (8.3%) and West Coast (8.7%) regions had the lowest incidence. Of the 2 subspecies isolated, *F. necrophorum* ssp. *necrophorum* is the more virulent strain of *F. necrophorum* due to its increased production of leukotoxin (Nagaraja and Chengappa, 1998). Leukotoxin protects the organism against phagocytosis, and in addition, the resulting lysis of leukocytes (white blood cells) releases products that are cytolytic to hepatic parenchymal cells, contributing to the accumulation of purulent and necrotic material in the liver (Tan et al., 1996), which forms the basis of a liver abscess.

Trueperella pyogenes was present in 14.8% of abscesses from fed-beef processing facilities and in 8.8% of abscesses from cull-beef processors (Table 3). However, *T. pyogenes* was not isolated from liver abscesses collected from every processor. *Trueperella pyogenes* was not detected in liver abscesses from fed-beef facilities in the Central Plains, Desert Southwest, and High Plains regions or at cull-beef facilities in the West Coast region. In contrast, *T. pyogenes* was present in 60% of Pacific Northwest samples. The Central Plains, Desert Southwest, High Plains, and West Coast regions average annual rainfall less than 50.8 cm and can reach temperatures in excess of 37°C in the summer, whereas the Pacific Northwest and Northeast regions can average 119 cm of rainfall and average maximum temperatures of 26°C in summer (US Climate Data). *Trueperella pyogenes* was primarily isolated from samples collected in geographical regions with colder climates and increased rainfall. Regardless of average temperature and rainfall, it is surprising that *T. pyogenes* was not isolated from several processing facilities.

Salmonella enterica was present in 27.5% of abscess samples collected from fed-beef processors and 16.5% of samples from cull-beef processors (Table 3). Similarly to *T. pyogenes*, *S. enterica* was not present in liver abscesses from every processing facility. *Salmonella enterica* was not isolated in samples collected from fed-beef processors in North Plains–A, North Plains–B, and the Pacific Northwest or cull-beef processors in the High Plains, Northeast, and West Coast. *Salmonella enterica* was recently discovered in beef liver abscesses (Amachawadi and Nagaraja, 2015), and at this time it is not known whether *S. enterica* is an etiologic agent or whether it enters after an abscess is initiated by *F. necrophorum*. *Salmonella enterica* has also been isolated from lymph nodes of slaughtered beef cattle (Gragg et al., 2013). When swine were orally inoculated with *S. enterica*, samples collected from lymphatic tissue and synovial fluid were positive for *Salmonella* (Broadway et al., 2015), suggesting that *Salmonella* is able to migrate from the GI tract to musculoskeletal lymph nodes. Furthermore, *S. enterica* has been isolated from retail ground beef (Zhao et al., 2002). Isolation of *S. enterica* from beef liver and lymphatic tissue indicates that *Salmonella* may present future food safety issues in a variety of beef products.

Although 3 major bacterial species were isolated in the study, not all species were present within the same liver

Table 3. Incidence of bacteria cultured from liver abscesses by region and processor type

		Incidence, %			
		Fusobacterium necrophorum			
Region	n	ssp. *necrophorum*	ssp. *funduliforme*	*Trueperella pyogenes*	*Salmonella enterica*
Fed-beef processors	189	79.9	24.3	14.8	27.5
Central Plains	25	88.0[a]	24.0[bc]	0.0[e]	52.0[c]
Desert Southwest	26	76.9[cd]	15.4[d]	0.0[e]	26.9[e]
High Plains	26	88.5[a]	15.4[d]	0.0[e]	84.6[a]
Northeast	28	75.0[d]	21.4[c]	10.7[c]	35.7[d]
North Plains–A	30	80.0[bc]	23.3[bc]	23.3[b]	0.0[f]
North Plains–B	29	75.9[cd]	27.6[b]	10.3[c]	0.0[f]
Pacific Northwest	25	76.0[cd]	44.0[a]	60.0[a]	0.0[f]
Cull-beef processors	91	76.9	17.6	8.8	16.5
High Plains	24	79.2[bcd]	8.3[e]	8.3[cd]	0.0[f]
Great Lakes	22	81.8[b]	27.3[b]	22.7[b]	68.2[b]
Northeast	22	77.3[bcd]	27.3[b]	4.5[de]	0.0[f]
West Coast	23	69.6[e]	8.7[e]	0.0[e]	0.0[f]
P-value		<0.01	<0.01	<0.01	<0.01

[a–f]Means within a column lacking common superscripts differ ($P < 0.05$).

abscess sample (Table 4). *Fusobacterium necrophorum*, regardless of subspecies, and *T. pyogenes* were present together in 14.3% of abscesses from fed-beef facilities and 8.8% of samples collected from cull-beef processing plants. However, these bacteria were not isolated together in samples cultured from the Central Plains, Desert Southwest, High Plains (fed beef), or West Coast regions, because no *T. pyogenes* was isolated from samples collected in these geographical regions. Of all the geographic regions, the Pacific Northwest had the greatest ($P < 0.01$) incidence (56.0%) of both *F. necrophorum* and *T. pyogenes* within the same liver abscess.

Table 4. Incidence of bacteria cultured in combination from liver abscesses by region and processor type

		Incidence,[1] %		
Region	n	*F. necrophorum* and *T. pyogenes*	*F. necrophorum* and *S. enterica*	*T. pyogenes* and *S. enterica*
Fed-beef processors	189	14.3	23.8	0.5
Central Plains	25	0.0[e]	44.0[c]	0.0[b]
Desert Southwest	26	0.0[e]	23.1[e]	0.0[b]
High Plains	26	0.0[e]	76.7[a]	0.0[b]
Northeast	28	10.7[c]	28.6[d]	3.6[b]
North Plains–A	30	23.3[b]	0.0[f]	0.0[b]
North Plains–B	29	10.3[c]	0.0[f]	0.0[b]
Pacific Northwest	25	56.0[a]	0.0[f]	0.0[b]
Cull-beef processors	91	8.8	16.5	2.2
High Plains	24	8.3[cd]	0.0[f]	0.0[b]
Great Lakes	22	22.7[b]	68.2[b]	9.1[a]
Northeast	22	4.6[de]	0.0[f]	0.0[b]
West Coast	23	0.0[e]	0.0[f]	0.0[b]
P-value		<0.01	<0.01	<0.01

[a–f]Means within a column lacking common superscripts differ ($P < 0.05$).

[1]*F. necrophorum* = *Fusobacterium necrophorum*; *T. pyogenes* = *Trueperella pyogenes*; *S. enterica* = *Salmonella enterica.*

The Pacific Northwest also had the greatest total abscess incidence, which may result from the increased incidence of *F. necrophorum* and *T. pyogenes*, together, within liver abscesses. A pathogenic synergy exists between *F. necrophorum* and *T. pyogenes* (Tadepalli et al., 2009). *Trueperella pyogenes* uses oxygen to create anaerobic conditions, which creates a favorable environment for *F. necrophorum*, whereas the waste product of *T. pyogenes* is lactic acid, which is the primary energy substrate of *F. necrophorum*. Furthermore, it has been demonstrated that mice inoculated with a subinfective dose of *F. necrophorum* developed liver abscesses after they were inoculated with *T. pyogenes* (Lechtenberg et al., 1993). These 2 pathogens aid in each other's survival within the host and ultimately result in increased liver abscess incidence.

Fusobacterium necrophorum and *S. enterica* were present together in 23.8% of abscess samples from fed-beef plants and 16.5% of samples collected from cull-beef processing plants. Within fed-beef processing facilities, cattle from the North Plains (A or B) and the Pacific Northwest regions did not exhibit both bacterial species within the same abscess, because samples cultured from these regions did not contain *S. enterica*. Within cull-beef processing facilities, samples collected from cattle in the High Plains, Northeast, and West Coast regions also did not have viable *F. necrophorum* and *S. enterica* within the same abscess sample. When these bacterial species did occur within the same abscess sample, samples from the High Plains fed-beef processor and the Great Lakes cull-beef processor had high frequencies together (76.7 and 68.2%, respectively), due to the high incidence of *S. enterica* that was present in both of those regions. It is possible that pathogenic synergy exists between *F. necrophorum* and *S. enterica*, because both have potent virulence factors and are capable of surviving in various environments; however, *S. enterica* was only recently discovered in beef liver abscesses (Amachawadi and Nagaraja, 2015) and the interactions that exist between these 2 bacterial species are yet to be fully defined.

Finally, *T. pyogenes* and *S. enterica* were present together in 0.5% of abscess samples from fed-beef processing facilities and 2.2% of samples from cull-beef processing facilities. The combination of these 2 pathogens within the same abscess was infrequent, with occurrence only in samples from 2 regions (Northeast fed-beef and Great Lakes cull-beef facilities). Of the over 300 abscess samples cultured, only 3 abscesses had both *T. pyogenes* and *S. enterica* within the same liver abscess sample. Additionally, those 3 samples were the only abscesses that had all 3 bacterial species present.

Data exist on *Salmonella* in beef liver abscesses (Amachawadi and Nagaraja, 2015; Amachawadi and Nagaraja, 2016; Amachawadi et al., 2017); however, its ability to interact with *T. pyogenes* in these conditions is limited. Recent research has reported the incidence of *T. pyogenes* and *S. enterica* within the same liver abscess sample, with crossbred cattle having an incidence of 15.4% and fed Holsteins having an incidence of 5.8%, which was less than the mixed infection incidence of *F. necrophorum* and *S. enterica* or *F. necrophorum* and *T. pyogenes* (Amachawadi et al., 2017). Additional research is still needed to better understand the relationship between *T. pyogenes* and *S. enterica* within beef liver abscesses; however, these data suggest that there might be some competitive inhibition between these 2 bacteria, which may explain their rare incidence together within liver abscesses.

When segregated by abscess severity (Table 5), A+ abscesses had the greatest ($P < 0.01$) incidence rate for *F. necrophorum* ssp. *necrophorum* (100.0%) and *S. enterica* (27.7%), compared with A (62.2 and 23.3%, respectively) and A− (71.8 and 20.5%, respectively) abscesses. *Trueperella pyogenes* incidence increased ($P < 0.01$) as abscess severity increased from A− to A, but incidence did not differ ($P > 0.05$) between A and A+ abscesses (9.0, 13.3, and 13.9%, respectively). Generally, as abscess severity score increased, bacteriological incidence increased.

Once *S. enterica* was isolated, serogroup identification was determined for each isolate and frequency of each was segregated by liver score (Table 5). Of the 8 unique serotypes isolated, the most common serotypes observed were Anatum (20 isolates), Montevideo (18 isolates), and Lubbock (16 isolates). When liver abscesses were collected from cattle that originated from 22 feedlots in the Central Plains, Desert Southwest, and High Plains regions that were slaughtered in 6 abattoirs throughout Arizona, California, Colorado, and Kansas, researchers isolated 5 unique serotypes of *Salmonella* (Lubbock, Agona, Cerro, Give, and Muenster; Amachawadi et al., 2017). The greater diversity of *Salmonella* serotypes observed in this experiment is likely due to the increased diversity of geographical regions sampled. Although not from liver abscess samples, fecal samples from multiple feedlots have yielded results similar to what was observed in this experiment. Fecal samples from feedlot and range cattle have yielded other serotypes of *Salmonella*, with Anatum and Montevideo being the most common in feedlot cattle (Fedorka-Cray et al., 1998), whereas Oranienburg and Cerro were the most prevalent serotypes cultured from range cows (Dargatz et al., 2000). *Salmonella* are facultatively anaerobic pathogens that can rapidly adapt to new environments and are known to be rather virulent in anaerobic conditions (Amachawadi and Nagaraja, 2015). The presence of various serotypes of *Salmonella* in the feces of feedlot and range beef indicates that these pathogens are present in the GI tract, and if one serotype is able to pass through the epithelial lining of the gut, it is likely that others are able to enter portal circulation as well.

Bacterial Incidence by Cattle Type

Incidence of bacterial species was also segregated by cattle type (Table 6). Fed beef, regardless of region and individual type, had an 81.3% incidence of *F. necrophorum* ssp. *necrophorum*, 25.9% incidence of *F. necrophorum* ssp.

Table 5. *Fusobacterium necrophorum*, *Trueperella pyogenes*, and *Salmonella enterica* and serotype incidence by liver score

	Liver score							
	A− (n = 78)		A (n = 90)		A+ (n = 101)			
Item	No. isolated	%	No. isolated	%	No. isolated	%	*P*-value	Total
Bacterial species								
F. necrophorum								
ssp. *necrophorum*	56	71.8[b]	56	62.2[c]	101	100.0[a]	<0.01	
ssp. *funduliforme*	8	10.3[b]	22	24.4[a]	28	27.7[a]	<0.01	
Trueperella pyogenes	7	9.0[b]	12	13.3[a]	14	13.9[a]	<0.01	
Salmonella enterica	16	20.5[b]	21	23.3[b]	28	27.7[a]	<0.01	
Salmonella serotype								
Anatum	6	9.0	5	7.5	9	13.4		20
Give	1	1.5	0	0.0	2	3.0		3
Kentucky	0	0.0	1	1.5	4	6.0		5
Lubbock	3	4.5	8	11.9	5	7.5		16
Mbandaka	1	1.5	0	0.0	1	1.5		2
Montevideo	5	7.5	7	10.4	6	9.0		18
Reading	0	0.0	0	0.0	2	3.0		2
Schwarzengrund	0	0.0	1	1.5	0	0.0		1

[a–c]Means within a row lacking common superscripts differ ($P < 0.05$).

funduliforme, 14.5% incidence of *T. pyogenes*, and 29.5% incidence of *S. enterica*. Cull beef, regardless of region and individual type, had an 73.7% incidence of *F. necrophorum* ssp. *necrophorum*, 10.5% incidence of *F. necrophorum* ssp. *funduliforme*, 6.6% incidence of *T. pyogenes*, and 10.5% incidence of *S. enterica*. It is interesting to note that greater than 40% of fed Holstein samples contained *S. enterica*, and other than fed cattle from mixed lots and bulls, all cattle types had samples positive for all bacterial species selectively cultured. It is likely that bulls and cattle from mixed lots would have had samples positive for *F. necrophorum* ssp. *funduliforme*, *T. pyogenes*, or *S. enterica*, but those groups had low sample numbers and were not collected throughout all geographical regions.

Estimated Visceral Losses due to Liver Abscesses and Other Abnormalities

No differences ($P = 0.48$; Table 1) in total visceral losses ($/animal) were noted by region or cattle type ($P = 0.86$; Table 2). Fed-beef losses were estimated at $2.05/animal due to liver abscess and other abnormalities, whereas cull-

Table 6. Incidence of bacteria cultured from liver abscesses by cattle type

		Incidence, %			
		Fusobacterium necrophorum			
Type	n	ssp. *necrophorum*	ssp. *funduliforme*	*Trueperella pyogenes*	*Salmonella enterica*
Fed beef	193	81.3	25.9	14.5	29.5
Steer	87	79.3	26.4	10.3	33.3
Heifer	55	76.4	29.1	27.3	14.5
Holstein[1]	42	88.1	26.2	9.5	47.6
Mixed lot[2]	9	100.0	0.0	0.0	0.0
Cull beef	76	73.7	10.5	6.6	10.5
Bull	5	60.0	0.0	0.0	0.0
Dairy cow	44	70.5	9.1	4.5	13.6
Range cow	27	81.5	14.8	11.1	7.4

[1]Holstein includes Holstein steers (n = 41) and Holstein heifers (n = 1).

[2]Mixed lot includes steers and heifers.

beef losses were estimated at $1.05/animal. Total viscera losses are composed of losses due to liver abscess ($1.46/animal, fed beef; $0.60/animal, cull beef), losses due to liver contamination ($0.43/animal, fed beef; $0.23/animal, cull beef), and losses due to other abnormalities ($0.16/animal, fed beef; $0.22/animal, cull beef). Therefore, using calculated values for national, annual fed- and cull-beef slaughter cattle, viscera losses for fed beef are estimated at $53.1 million ($37.7 million due to liver abscesses, $11.1 million due to contamination, and $4.3 million due to other abnormalities) annually and $6.8 million ($3.9 million due to liver abscesses, $1.5 million due to contamination, and $1.4 million due to other abnormalities) for cull beef. Based on conservative estimates, liver abscesses and other abnormalities cost beef processors approximately $60 million annually in viscera losses.

APPLICATIONS

Liver abscesses in cattle significantly affect the beef industry (cull- and fed-beef processing), not only from the loss of a condemned liver and often all viscera, but also through reduced animal performance, diminished carcass yield, and decreased processor efficiency. Generally, as size of the abscess increased, bacteriological incidence increased. However, *T. pyogenes* and *S. enterica* were rarely present together within the same abscess. Using conservative estimates, viscera losses were approximated at $60 million annually, with liver abscesses accounting for $41.6 million in losses. Because the incidence and severity of abscesses are increased in Holsteins, their potential to negatively affect the industry is magnified, so additional management practices may need to be implemented to minimize their potential negative effects on the beef industry.

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LITERATURE CITED

Addah, W., J. Baah, and T. A. McAllister. 2016. Effect of silage chop length on feed intake and feeding behaviour of finishing feedlot steers. Acta Agric. Scand. A Anim. Sci. 66:106–114. https://doi.org/10.1080/09064702.2016.1267789.

Allen, M. S. 1996. Physical constraints on voluntary intake of forages by ruminants. J. Anim. Sci. 74:3063–3075. https://doi.org/10.2527/1996.74123063x.

Amachawadi, R. G., and T. G. Nagaraja. 2015. First report of anaerobic isolation of *Salmonella enterica* from liver abscesses of feedlot cattle. J. Clin. Microbiol. 53:3100–3101. https://doi.org/10.1128/JCM.01111-15.

Amachawadi, R. G., and T. G. Nagaraja. 2016. Liver abscesses in cattle: A review of incidence in Holsteins and of bacteriology and vaccine approaches to control in feedlot cattle. J. Anim. Sci. 94:1620–1632. https://doi.org/10.2527/jas.2015-0261.

Amachawadi, R. G., T. J. Purvis, B. V. Lubbers, J. W. Homm, C. L. Maxwell, and T. G. Nagaraja. 2017. Bacterial flora of liver abscesses in crossbred beef cattle and Holstein steers fed finishing diets with or without tylosin. J. Anim. Sci. 95:3425–3434. https://doi.org/10.2527/jas2016.1198.

Anderson, K. L., T. G. Nagaraja, and J. L. Morrill. 1987. Ruminal metabolic development in calves weaned conventionally or early. J. Dairy Sci. 70:1000–1005. https://doi.org/10.3168/jds.S0022-0302(87)80105-4.

Asem-Hiablie, S., C. A. Rotz, R. Stout, and K. Fisher. 2017. Management characteristics of beef cattle production in the western United States. Prof. Anim. Sci. 33:461–471. https://doi.org/10.15232/pas.2017-01618.

Asem-Hiablie, S., C. A. Rotz, R. Stout, and S. Place. 2018. Management characteristics of beef cattle production in the eastern United States. Prof. Anim. Sci. 34:311–325. https://doi.org/10.15232/pas.2018-01728.

Asem-Hiablie, S., C. A. Rotz, R. Stout, and K. Stackhouse-Lawson. 2016. Management characteristics of beef cattle production in the northern plains and midwest regions of the United States. Prof. Anim. Sci. 32:736–749. https://doi.org/10.15232/pas.2016-01539.

Beauchemin, K. A., and K. M. Koenig. 2005. Feedlot cattle diets based on barley or corn supplemented with dry corn gluten feed evaluated using the NRC and CNCPS beef models. Can. J. Anim. Sci. 85:365–375. https://doi.org/10.4141/A04-060.

Broadway, P. R., J. A. Carroll, J. C. Brooks, J. R. Donaldson, N. C. Sanchez, T. B. Schmidt, T. R. Brown, and T. R. Callaway. 2015. *Salmonella* prevalence of lymph nodes and synovial fluid of orally inoculated swine. Agric. Food Anal. Bacteriol. 5:6–14.

Brown, T. R., and T. E. Lawrence. 2010. Association of liver abnormalities with carcass grading performance and value. J. Anim. Sci. 88:4037–4043. https://doi.org/10.2527/jas.2010-3219.

Burken, D. B., B. L. Nuttelman, J. L. Gramkow, A. L. McGee, K. M. Sudbeck, S. E. Gardine, T. C. Hoegemeyer, T. J. Klopfenstein, and G. E. Erickson. 2017. Effects of agronomic factors on yield and quality of whole corn plants and the impact of feeding high concentrations of corn silage in diets containing distillers grains to finishing cattle. Transl. Anim. Sci. 1:367–381. https://doi.org/10.2527/tas2017.0045.

Checkley, S. L., E. D. Janzen, J. R. Campbell, and J. J. McKinnon. 2005. Efficacy of vaccination against *Fusobacterium necrophorum* infection for control of liver abscesses and footrot in feedlot cattle in western Canada. Can. Vet. J. 46:1002–1007.

Dargatz, D. A., P. J. Fedorka-Cray, S. R. Ladely, and K. E. Ferris. 2000. Survey of *Salmonella* serotypes shed in feces of beef cows and their antimicrobial susceptibility patterns. J. Food Prot. 63:1648–1653. https://doi.org/10.4315/0362-028X-63.12.1648.

Doré, E., G. Fecteau, P. Hélie, and D. Francoz. 2007. Liver abscesses in Holstein dairy cattle: 18 Cases (1992–2003). J. Vet. Intern. Med. 21:853–856. https://doi.org/10.1111/j.1939-1676.2007.tb03031.x.

Duff, G. C., and C. P. McMurphy. 2007. Feeding Holstein steers from start to finish. Vet. Clin. North Am. Food Anim. Pract. 23:281–297. https://doi.org/10.1016/j.cvfa.2007.04.003.

Eastwood, L. C., C. A. Boykin, M. K. Harris, A. N. Arnold, D. S. Hale, C. R. Kerth, D. B. Griffin, J. W. Savell, K. E. Belk, D. R. Woerner, J. D. Hasty, R. J. Delmore Jr., J. N. Martin, T. E. Lawrence, T. J. McEvers, D. L. VanOverbeke, G. G. Mafi, M. M. Pfeiffer, T. B. Schmidt, R. J. Maddock, D. D. Johnson, C. C. Carr, J. M. Scheffler, T. D. Pringle, and A. M. Stelzleni. 2017. National Beef Quality Audit-2016: Transportation, mobility, and harvest-floor assessments of targeted characteristics that affect quality and value of cattle, carcasses, and by-products. Transl. Anim. Sci. 1:229–238. https://doi.org/10.2527/tas2017.0029.

Eastwood, L. C., M. K. Harris, C. A. Boykin, A. N. Arnold, K. B. Gehring, D. S. Hale, C. R. Kerth, D. B. Griffin, J. W. Savell, K. E. Belk, D. R. Woerner, J. D. Hasty, R. J. Delmore Jr., J. N. Martin, T. E. Lawrence, T. J. McEvers, D. L. VanOverbeke, G. G. Mafi, M. M. Pfeiffer, T. B. Schmidt, R. J. Maddock, D. D. Johnson, C. C. Carr, J. M. Scheffler, T. D. Pringle, and A. M. Stelzleni. 2018. National Beef Quality Audit-2016: Comparisons between fed steers/heifers and market cows/bulls for by-product condemnations. Meat Muscle Biol. 2:101–102. https://doi.org/10.22175/rmc2018.091.

fedorka-cray, p. j., d. a. dargatz, l. a. thomas, and j. t. gray. 1998. survey of *salmonella* serotypes in feedlot cattle. J. Food Prot. 61:525–530. https://doi.org/10.4315/0362-028X-61.5.525.

Franklin, S. T., D. M. Amaral-Phillips, J. A. Jackson, and A. A. Campbell. 2003. Health and performance of Holstein calves that suckled or were hand-fed colostrum and were fed one of three physical forms of starter. J. Dairy Sci. 86:2145–2153. https://doi.org/10.3168/jds.S0022-0302(03)73804-1.

Gragg, S. E., G. H. Loneragan, M. M. Brashears, T. M. Arthur, J. M. Bosilevac, N. Kalchayanand, R. Wang, J. W. Schmidt, J. C. Brooks, S. D. Shackelford, T. L. Wheeler, T. R. Brown, T. S. Edrington, and D. M. Brichta-Harhay. 2013. Cross-sectional study examining *Salmonella enterica* carriage in subiliac lymph nodes of cull and feedlot cattle at harvest. Foodborne Pathog. Dis. 10:368–374. https://doi.org/10.1089/fpd.2012.1275.

Hadley, G. L., C. A. Wolf, and S. B. Harsh. 2006. Dairy cattle culling patterns, explanations, and implications. J. Dairy Sci. 89:2286–2296. https://doi.org/10.3168/jds.S0022-0302(06)72300-1.

Hale, W. H. 1985. Liver abscesses and founder. Anim. Nutr. Health Sep.:12–20.

Harris, M. K., L. C. Eastwood, C. A. Boykin, A. N. Arnold, K. B. Gehring, D. S. Hale, C. R. Kerth, D. B. Griffin, J. W. Savell, K. E. Belk, D. R. Woerner, J. D. Hasty, R. J. Delmore Jr., J. N. Martin, T. E. Lawrence, T. J. McEvers, D. L. VanOverbeke, G. G. Mafi, M. M. Pfeiffer, T. B. Schmidt, R. J. Maddock, D. D. Johnson, C. C. Carr, J. M. Scheffler, T. D. Pringle, and A. M. Stelzleni. 2018. National Beef Quality Audit–2016: Assessment of cattle hide characteristics, offal condemnations, and carcass traits to determine the quality status of the market cow and bull beef industry. Transl. Anim. Sci. 2:37–49. https://doi.org/10.1093/tas/txx002.

Hicks, R. B., F. N. Owens, D. R. Gill, J. W. Oltjen, and R. P. Lake. 1990. Daily dry matter intake by feedlot cattle: Influence of breed and gender. J. Anim. Sci. 68:245–253. https://doi.org/10.1093/ansci/68.1.245.

Kaplan, R. M. 2001. Fasciola hepatica: A review of the economic impact in cattle and considerations for control. Vet. Ther. 2:40–50.

Kristensen, N. B., J. Sehested, S. K. Jensen, and M. Vestergaard. 2007. Effect of milk allowance on concentrate intake, ruminal environment, and ruminal development in milk-fed Holstein calves. J. Dairy Sci. 90:4346–4355. https://doi.org/10.3168/jds.2006-885.

Langworth, B. F. 1977. *Fusobacterium necrophorum*: Its characteristics and role as an animal pathogen. Bacteriol. Rev. 41:373–390. https://doi.org/10.1128/br.41.2.373-390.1977.

Lechtenberg, K. F., T. G. Nagaraja, H. W. Leipold, and M. M. Chengappa. 1988. Bacteriologic and histologic studies of hepatic abscesses in cattle. Am. J. Vet. Res. 49:58–62.

Lechtenberg, K. F., T. G. Nagaraja, and J. C. Parrot. 1993. The role of *Actinomyces pyogenes* in liver abscess formation. Scientific Update on Rumensin/Tylan for the Professional Feedlot Consultant. E1-6. Elanco Anim. Health.

MacDonald, J. M., W. D. McBride, E. O'Donoghue, R. F. Nehring, C. Sandretto, and R. Mosheim. 2007. Profits, Costs, and the Changing Structure of Dairy Farming. USDA Economic Research Report Number 47. USDA.

Nagaraja, T., and R. Smith. 2000. Liver abscesses in beef cattle: Potential for dairy monitoring? Pages 65–68 in Proc. 33rd Annu. Conf. Am. Assoc. Bovine Pract. Am. Assoc. Bovine Pract.

Nagaraja, T. G., and M. M. Chengappa. 1998. Liver abscesses in feedlot cattle: A review. J. Anim. Sci. 76:287–298. https://doi.org/10.2527/1998.761287x.

Nagaraja, T. G., and E. C. Titgemeyer. 2007. Ruminal acidosis in beef cattle: The current microbiological and nutritional outlook. J. Dairy Sci. 90:E17–E38. https://doi.org/10.3168/jds.2006-478.

Nelson, M. L., J. R. Busboom, J. D. Cronrath, L. Falen, and A. Blankenbaker. 2000. Effects of graded levels of potato by-products in barley-and corn-based beef feedlot diets: I. Feedlot performance, carcass traits, meat composition, and appearance. J. Anim. Sci. 78:1829–1836. https://doi.org/10.2527/2000.7871829x.

Nordlund, K. V., N. B. Cook, and G. R. Oetzel. 2004. Investigation strategies for laminitis problem herds. J. Dairy Sci. 87:E27–E35. https://doi.org/10.3168/jds.S0022-0302(04)70058-2.

Owens, F. N., D. S. Secrist, W. J. Hill, and D. R. Gill. 1998. Acidosis in cattle: A review. J. Anim. Sci. 76:275–286. https://doi.org/10.2527/1998.761275x.

Rezac, D. J., D. U. Thomson, S. J. Bartle, J. B. Osterstock, F. I. Prouty, and C. D. Reinhardt. 2014b. Prevalence, severity, and relationships of lung lesions, liver abnormalities, and rumen health scores measured at slaughter in beef cattle. J. Anim. Sci. 92:2595–2602. https://doi.org/10.2527/jas.2013-7222.

Rezac, D. J., D. U. Thomson, M. G. Siemens, F. L. Prouty, C. D. Reinhardt, and S. J. Bartle. 2014a. A survey of gross pathologic conditions in cull-cows at slaughter in the Great Lakes region of the United States. J. Dairy Sci. 97:4227–4235. https://doi.org/10.3168/jds.2013-7636.

Roeber, D. L., P. D. Mies, C. D. Smith, K. E. Belk, T. G. Field, J. D. Tatum, J. A. Scanga, and G. C. Smith. 2001. National market cow and bull beef quality audit—1999: A survey of producer-related defects in market cows and bulls. J. Anim. Sci. 79:658–665. https://doi.org/10.2527/2001.793658x.

Smith, H. R. 1940. Beef liver condemnations. J. Anim. Sci. 1940:272–276.

Tadepalli, S., S. K. Narayanan, G. C. Stewart, M. M. Chengappa, and T. G. Nagaraja. 2009. *Fusobacterium necrophorum*: A ruminal bacterium that invades liver to cause abscesses in cattle. Anaerobe 15:36–43. https://doi.org/10.1016/j.anaerobe.2008.05.005.

Tan, Z. L., T. G. Nagaraja, and M. M. Chengappa. 1994. Biochemical and biological characterization of ruminal *Fusobacterium necrophorum*. FEMS Microbiol. Lett. 120:81–86. https://doi.org/10.1111/j.1574-6968.1994.tb07011.x.

Tan, Z. L., T. G. Nagaraja, and M. M. Chengappa. 1996. *Fusobacterium necrophorum* infections: Virulence factors, pathogenic mechanism and control measures. Vet. Res. Commun. 20:113–140. https://doi.org/10.1007/BF00385634.

USDA. 2016a. Oct. 2015–Mar. 2016. NW_LS441, By-Product Drop Value (Steer). Accessed Jan. 27, 2017. https://www.ams.usda.gov/mnreports/nw_ls441.txt.

USDA. 2016b. Oct. 2015–Mar. 2016. NW_LS444, Weekly USDA By-Product Drop Value (Cow). Accessed Jan. 27, 2017. https://www.ams.usda.gov/mnreports/nw_ls444.txt.

USDA. 2017. SJ_LS710, Estimated daily Livestock Slaughter under Federal Inspection. Accessed Jan. 27, 2017. https://www.ams.usda.gov/mnreports/sj_lj710.txt.

Vogel, G. J., and J. C. Parrott. 1994. Mortality survey in feed yards: The incidence of death from digestive, respiratory and other causes in feed yards on the Great Plains. Compend. Contin. Educ. Pract. Vet. 16:227–234.

Zhao, T., M. P. Doyle, P. J. Fedorka-Cray, P. Zhao, and S. Ladely. 2002. Occurrence of *Salmonella enterica* serotype *Typhimurium* DT104A in retail ground beef. J. Food Prot. 65:403–407. https://doi.org/10.4315/0362-028X-65.2.403.

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