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REVIEW

Review: Control of liver abscesses in feedlot cattle: A review[1]

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ABSTRACT

Published literature was reviewed to provide an overview of the historical prevalence and methods of controlling liver abscesses (LA) in feedlot cattle. Liver abscesses are typically categorized as mild, moderate, or severe, with severe LA most often being associated with reductions in performance. The prevalence of LA in beef-breed steers increased by 25% between 2008 and 2013; however, the prevalence in Holstein steers tripled over the same period. Regionally, the greatest prevalence has been observed in Kansas, eastern Colorado, and western Nebraska, and the lowest prevalence has been observed in the Midwest and the desert southwest. Fusobacterium necrophorum and Trueperella pyogenes are most commonly associated with LA, although F. necrophorum is likely the primary causative pathogen. Liver abscesses are often, but not always, associated with perforations in the rumen wall. Tylosin phosphate is commonly fed to control LA. Feeding elevated levels of roughage during growing and finishing periods results in a dramatic reduction in LA; overprocessing of dietary roughage reduces its effectiveness. Grain processing has marked effects on ruminal starch availability but has minimal effect on LA; inclusion of fibrous by-product feeds also does not mitigate prevalence of LA. Vaccination against F. necrophorum has shown little benefit in field application. Providing a source of true scratch-factor to the rumen, either by increasing the percentage of coarse roughage included in the TMR or by periodically providing coarse hay apart from the TMR, appears to be the most effective method of reducing LA.

Key words: cattle, feedlot, grain processing, liver abscess, roughage

INTRODUCTION

Liver abscesses (**LA**) are the primary cause of liver condemnation in feedlot cattle slaughtered in the United States, averaging 67% of all liver abnormalities (Brown and Lawrence, 2010). Feeding high-energy, grain-based finishing diets low in roughage, common in the feedlot industries in the United States, Canada, Mexico, Europe, South Africa, and Japan, is associated with elevated prevalence of liver abscesses (Nagaraja et al., 1996). Although all LA may affect animal performance to some degree, the most severe LA have the greatest effect and may reduce the value of beef carcasses by $38 per animal (Brown and Lawrence, 2010); in addition, there is concern for animal well-being in animals with severe liver abscesses. Because of the negative economic effect of LA, there is interest in prevention and control of LA in feedlot cattle. Nagaraja and Chengappa (1998) provided an excellent, thorough review of this topic. The objectives of the present review are to provide an update to that summary and to emphasize practical management factors germane to this issue.

PREVALENCE

Livers that are free from abscesses are classified as normal; livers categorized as having mild to moderate LA display ≤4 abscesses or resolved abscess scars ≤4 cm in diameter; livers categorized as having severe LA are livers displaying ≥1 abscesses >4 cm in diameter or >4 abscesses >2 cm in diameter (Elanco, 2014).

Prevalence of total LA (mild, moderate, and severe) ranges from close to 0% to greater than 70%, depending on several factors. However, the mean prevalence of total LA in conventionally managed United States feedlot cattle more commonly ranges from 10 to 20%, and the prevalence of severe LA commonly ranges from 4 to 6% (Davis et al., 2007; Brown and Lawrence, 2010; Rezac et al., 2014). Prevalence of LA varies by geographical location within the United States, with cattle slaughtered in the semi-arid plains of the central United States having 22 and 14% total and severe LA, respectively, and cattle slaughtered in the midwestern states, the southern plains, and the desert southwest averaging 13 and 4% total and severe LA, respectively, with the

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Pacific Northwest and the northern plains being intermediate averaging 19 and 7% total and severe LA, respectively (Elanco, 2014).

There has been a recent slight upward trend in the prevalence of LA in beef-breed steers, with an annual average that previously oscillated around 12% total LA from 2003 through 2008 rising steadily each year thereafter to 16% in 2013 (Elanco, 2014). However, the increase in prevalence of LA in Holstein steers has been much more noteworthy, rising steadily from 12% in 2003 and 2004 to 55% in 2013. Most of this increase has been observed in Holstein steers fed and slaughtered in the central high plains, where prevalence of LA in Holstein steers averaged 6 and 48% total and severe LA, respectively. Prevalence of LA in Holsteins fed and slaughtered in other parts of the United States has not changed dramatically, averaging 23 and 9% total and severe LA, respectively (Elanco, 2014). Prevalence also fluctuates seasonally, increasing roughly 4 percentage units for cattle slaughtered during the summer months versus those cattle slaughtered during the winter months (Elanco, 2014). Conversely, Brown and Lawrence (2010) reported that cattle slaughtered in the spring (March, April, and May) had a numerically greater percentage of liver condemnations for all causes and cattle slaughtered in the months of July, August, and September had numerically fewer liver condemnations.

One theory as to why calf-fed Holsteins suffer so much greater prevalence of LA versus beef-breed cattle is the extended duration of total days on feed. Calf-fed Holsteins, which typically arrive at feedlots weighing 130 to 180 kg and are fed a low-roughage, high-energy finishing diet for 300 to 400 d, have a much greater opportunity to develop LA versus their beef-breed counterparts, which typically arrive weighing 230 to 400 kg and are finished for only 120 to 240 d. Another theory has been proposed that management practices specific to the central plains region may contribute to increased prevalence of LA. This theory is unlikely because animal management has not changed significantly in the time period in question and because animal management does not differ substantially in the central, southern, and northern high plains. It has been suggested that LA organisms in calves raised in western calf ranches and subsequently shipped to feedlots in the central plains have developed resistance to tylosin. This theory is unlikely given the fact that LA prevalence has increased rapidly, has increased in non-Holstein, non-calf-ranch beef-breed cattle, and has not increased in other geographies where calves originating in these same calf ranches are also finished. Given the aforementioned evidence of a significant increase in LA in both beef breeds and in Holsteins, and that the increase has been observed only in the central high plains, over a short span of time, it is arguable that feedyards in the central high plains may have an infective pathogenic organism causing LA that simply is not extant in other geographic regions. This theory will require deeper investigation to substantiate or refute.

EFFECTS ON PERFORMANCE

Although mild and moderate LA have no or limited effects on animal performance (Davis et al., 2007; Fox et al., 2009; Brown and Lawrence, 2010), severe LA may reduce ADG by 0.06 to 0.20 kg (Brink et al., 1990; Fox et al., 2009; Rezac et al., 2014). Feed intake and feed conversion are also impeded by severe LA, reducing intake by 5% and gain-to-feed by 14% (Brink et al., 1990).

Presence of severe LA also may reduce HCW by 4 to 36 kg (Montgomery, 1985; Fox et al., 2009; Rezac et al., 2014). Severe LA, if associated with adhesion of the LA to the internal body-cavity wall results in even greater reduction in HCW. Davis et al. (2007) reported that the presence of severe LA was associated with 3.2-kg-lighter HCW but severe LA observed in conjunction with carcass adhesion was associated with 13.2-kg-lighter HCW; Brown and Lawrence (2010) reported that adhesions increased the loss in HCW by 3 kg in one comparison and by 8.7 kg in a second comparison. At least a portion of the increased loss in HCW may be trim; Montgomery (1985) reported an increase in trim loss of 0.43 percentage units for carcasses with severe LA, and Brown and Lawrence (2010) reported that carcasses with severe LA had 0.26 percentage units lower DP, possibly attributable to trim loss.

Carcass quality may also be reduced in cattle with severe LA. Whereas Davis et al. (2007) reported no difference in marbling score between cattle with normal livers and those with LA, Fox et al. (2009) reported that 7 percentage units fewer cattle graded Choice if severe LA were present versus cattle with normal livers. Brown and Lawrence (2010) reported a reduction in marbling score but also reductions in YG, fat depth, and percent KPH fat in cattle with severe LA versus cattle with normal livers.

Based on a reduction in carcass weight of 10 kg for cattle with severe LA versus cattle with normal, healthy livers, and the current carcass value of beef in the United States of $5.21/kg carcass weight (USDA, 2014), each animal with severe LA has reduced value of more than $52. If potential reductions in feed efficiency and carcass quality are also considered, the total loss in value is potentially even greater.

ETIOLOGY AND PATHOLOGY

Several different bacteria are commonly isolated from LA, including *Fusobacterium necrophorum* (Berg and Scanlan, 1982), *Trueperella pyogenes* (Calkins and Scrivner, 1967), *Bacteroides* spp. (Berg and Scanlan, 1982), *Clostridium* spp. (Simon and Stovell, 1971), *Pasteurella* spp. (Simon and Stovell, 1971), *Peptostreptococcus* spp. (Berg and Scanlan, 1982), *Staphylococcus* spp. (Berg and Scanlan, 1982), and *Streptococcus* spp. (Simon and Stovell, 1971), as well as other, not-yet-identified bacterial species, both gram-positive and gram-negative

(Nagaraja and Chengappa, 1998). It is conceivable that additional organism or organisms may be involved in the recent increase in LA. T. G. Nagaraja (2014, personal communication) at Kansas State University recently isolated a *Salmonella* organism from LA that had not been previously reported to be present in LA. However, *F. necrophorum* is the most commonly isolated pathogen found in LA, and *T. pyogenes* is the second most frequently identified (Nagaraja and Chengappa, 1998; Nagaraja et al., 1999a).

Although commonly found as the lone pathogenic organism in LA, *F. necrophorum* is more often found in conjunction with other organisms in LA, most commonly *T. pyogenes* (Nagaraja et al., 1999a). Two primary virulence factors of *F. necrophorum*, leukotoxin and endotoxic lipopolysaccharide, are believed to explain the ability of this organism to survive the potent protective mechanisms of the liver, creating a beneficial environment within the liver, allowing other bacteria to follow (Tan et al., 1996), and greater production of these factors may also explain why subspecies *F. necrophorum necrophorum* is more commonly isolated from LA than subspecies *funduliforme* (Berg and Scanlan, 1982).

Fusobacterium necrophorum is commonly found in the rumen (Berg and Scanlan, 1982; Tan et al., 1994a) but increases roughly 10-fold when cattle are switched from a roughage diet to a grain-based diet (Tan et al., 1994b). Nagaraja and Chengappa (1998) speculate that the preference of *F. necrophorum* for lactate as fermentative substrate as opposed to sugars, coupled with the increased abundance of lactate in the rumen of cattle fed high-grain diets, explains the rise in numbers of *F. necrophorum*.

Although a direct mechanism and pathway for infection of the liver has not been documented, it is widely accepted that rumenitis—damage of the ruminal epithelium—is the primary predisposing factor (Nagaraja and Chengappa, 1998). Smith (1944), Jensen et al. (1954), and Rezac et al. (2014) documented a high correlation between ruminal ulcers and the presence of LA; however, Weiser et al. (1966) found no such correlation. Unlike cattle, intensively fed sheep, even when fed high-grain, low-roughage diets, rarely experience rumenitis or LA (Ørskov, 2002). Fell et al. (1972) reported that including cattle hair in high-grain diets fed to sheep resulted in a dramatic increase in prevalence of rumenitis, suggesting that grooming behavior of feedlot cattle, licking themselves or others, results in some of the damage and perforation of the rumen wall, leading to bacterial exodus and subsequent LA.

Damage to the rumen epithelium, either by excessive acid load or by physical damage, results in colonization of the ulcerated site by *F. necrophorum* (Kanoe et al., 1978). The bacteria then enter the portal blood, which is subsequently filtered by the liver, where the bacteria may colonize, resulting in the formation of LA (Nagaraja and Chengappa, 1998). Although anaerobic, *F. necrophorum* is able to overcome the oxygen-rich environment of the liver. This may be due to a synergism with other, facultative aerobic bacteria such as *T. pyogenes*, which can thrive in the presence of oxygen, and which produces lactate—a preferred substrate of *F. necrophorum*—as a primary fermentation end product (Takeuchi et al., 1983). In return, the abundant leukotoxin and endotoxic lipopolysaccharide production of *F. necrophorum*, along with other virulence factors (Nagaraja and Chengappa, 1998), neutralize the phagocytic cells of the liver and create a safe microenvironment for other, less virulent bacteria (Tan et al., 1996).

A complex combination of circumstances appear to intersect, resulting in LA in feedlot cattle. The dramatic rise in ruminal *F. necrophorum* during and after transition from a roughage diet to a high-grain diet increases the critical mass of the suspect pathologic population. Lack of physical scratch supplied by low-roughage diets results in altered ruminal papillae structure predisposing the rumen to physical damage. Perforation of the ruminal epithelium by the extensive acid accumulation of the rapid fermentation of grain provides a pathway for pathogenic bacteria. The destructive virulence factors and the potency of the counter-defenses of *F. necrophorum* against the defenses of the liver combine to create the synchrony of events and circumstances necessary for establishment of LA.

METHODS OF CONTROL

Antimicrobials

The most common method of controlling LA in finishing cattle in the United States is continuous feeding of antimicrobial compounds; the most commonly used antimicrobial for this purpose is tylosin phosphate. Although the majority of United States feedlots routinely feed ionophore antibiotics, *F. necrophorum* is not susceptible to ionophores (Baba et al., 1989; Lechtenberg and Nagaraja, 1989). Meyer et al. (2013) reported that feeding monensin alone in the finishing diet did not affect incidence of LA, but inclusion of tylosin in addition to monensin reduced prevalence of total and severe LA.

Feeding tylosin reduces concentration of *F. necrophorum* in the rumen by 80 to 90% (Nagaraja et al., 1999b) in cattle fed an 85% concentrate diet, and feeding tylosin reduces prevalence of LA by 40 to 70% (Nagaraja and Chengappa, 1998). However, even when tylosin is fed, LA commonly occur in 12 to 18% of feedlot cattle (Elanco, 2014), compared with the 45% observed when tylosin is not fed (Brown and Lawrence, 2010). Nagaraja and Chengappa (1998) offered 3 possible reasons that feeding tylosin does not provide 100% control: (1) tylosin may reduce *F. necrophorum* populations allowing other bacteria to increase and cause the infection; (2) feeding tylosin may allow development of antimicrobial resistance by target bacteria; and (3) feeding tylosin may not provide sufficient concentrations of tylosin in the rumen and in the blood to eliminate all *F. necrophorum* and *T. pyogenes* to control 100% of potential infections.

Other antimicrobials are both effective and approved (within the United States) for control of LA. Chlortetracycline, fed at 70 mg per animal per day, reduces prevalence of LA by 21 percentage units versus negative control and reduces prevalence of severe LA by 35% (Brown et al., 1975). In those same comparisons, however, inclusion of tylosin in the feed to provide 75 mg per animal per day reduced total and severe LA prevalence by 67 and 85%, respectively, suggesting greater efficacy for tylosin versus chlortetracycline at the doses used. In addition, Virginiamycin, when fed at 27.3 mg/kg of diet DM, reduced prevalence of total and severe LA by 39 and 37%, respectively (Rogers et al., 1995).

Meyer et al. (2007) fed a proprietary blend of essential oils and reported nonsignificant, numerical decreases in both total and severe LA. Feeding one of these essential oils, limonene, at either 10, 40, or 80 mg/kg of diet DM, Samii (2014) reported reductions in ruminal concentrations of *F. necrophorum* by as much as 0.5 $\log_{10}$.

With increasing scrutiny of antimicrobial use in animal-protein production by consumers, advocacy groups, legislators, and regulatory agencies, it will be of value to examine all factors contributing to LA and all factors that may be altered to control prevalence of LA in the future.

Roughage Level and Form

Because LA is associated with acute or chronic acidosis and the potential for development of rumenitis, roughage level is presumed to influence the prevalence of LA. Zinn and Plascencia (1996) reported that increasing the amount of ground alfalfa hay in the finishing diet from 10 to 30% reduced the prevalence of LA from 15 to 2%; mean ruminal pH for the 10%- versus the 30%-roughage diets was 5.79 versus 6.02, respectively. Gill et al. (1979) reported that increasing the amount of cottonseed hulls included in the finishing diet from 5 to 15% decreased the prevalence of LA from 41 to 24%. In diets based on whole, high-moisture corn, Loerch and Fluharty (1998) reported that increasing the amount of corn silage from 0 to 15% reduced the percentage of condemned livers from 29 to 15%, and Bartle et al. (1994) reported that increasing the level of chopped alfalfa hay or cottonseed hulls from 10% to 20 or 30% in steam-flaked sorghum-based finishing diets reduced the prevalence of LA from 14% to 4 and 6%, respectively. Contrary to the aforementioned results, Kreikemeier et al. (1990) reported that increasing the roughage level (1:1 blend of corn silage and chopped alfalfa hay) from 0% to 5, 10, or 15% in steam-rolled wheat-based finishing diets actually resulted in a numerical increase in, rather than a decrease in, LA.

Elevating the roughage level late in the finishing period reduces LA. Loerch and Fluharty (1998) found that when roughage level was decreased from 30% early in the finishing phase to 15% in the middle, and then to 0% roughage late in the finishing phase, percentage of condemned livers was more than double compared with when roughage level was increased over time from 0 to 15% and then to 30% late in the finishing phase (25.8 vs. 11.0% LA, respectively). Bartle et al. (1994) reported that feeding 10% roughage early during finishing but decreasing to 2% roughage during the final 28 d before slaughter resulted in numerically greater incidence of LA (9 and 6% for diets containing steam-flaked sorghum grain and whole-shelled corn diets, respectively) versus feeding 2% roughage early in the finishing period and increasing to 10% during the final 28 d before slaughter (0% for both grain types). Elevating the roughage late in the feeding period was similar to feeding 10% roughage throughout with respect to incidence of LA, suggesting that LA may occur early in the finishing phase but increasing the roughage late in the finishing phase and providing sufficient time the incidence of LA may return to zero.

That is not to imply that roughage levels fed early in life are inconsequential. Checkley et al. (2005) reported when cattle were finished for the final 112 d on a common, high-grain diet, cattle grown early in the finishing period using a forage-based diet had greatly reduced prevalence of LA (6%) versus cattle that had been grown on a limit-fed, grain-based diet (27%). Reinhardt et al. (1998) reported that growing Holstein steers for 112 d using either ad libitum access to a 68% corn silage–based diet or limit feeding a diet based on steam-flaked corn (25% corn silage) resulted in 7 and 8% prevalence of LA, respectively, compared with 18% when cattle had ad libitum access to a finishing diet based on steam-flaked corn throughout the growing and finishing period. It is believed that over time, LA eventually become devoid of pathogenic bacteria, form sterile scar tissue, and eventually can completely heal (Lechtenberg and Nagaraja, 1991), which suggests that in cattle that are placed on a very low–roughage diet early in the finishing phase but which are then transitioned to a greater roughage level may, in fact, develop LA early during finishing, but which then heal after switching to a diet containing a greater percentage of roughage. Because roughage is costly on a per-unit-of-net-energy basis, and it is logistically challenging to manage both as a commodity and when included as a portion of the finishing diet, it bears considering that roughage could be limited early during finishing but elevated late in the finishing phase, shortly before slaughter, to mitigate any lingering effects on LA.

Although roughage level provided during growing and finishing appears to influence incidence of LA, form of the roughage provided also appears to influence prevalence. Utley et al. (1973) reported that when 20% whole peanut hulls included in ground corn–based finishing diets was replaced with either ground or ground-and-pelleted peanut hulls, LA increased from 4% to 52 and 59%, respectively. Calderon-Cortes and Zinn (1996) fed finishing diets based on steam-flaked corn containing either 8 or 16% chopped alfalfa hay, wherein the hay was chopped through either a 2.5- or 7.6-cm screen, and reported 12.5% LA when the more finely chopped hay was fed at either 8 or 16% and 0% LA when the more coarsely chopped hay was fed at either 8 or 16%, suggesting that inclusion of 8% hay was adequate to prevent LA, provided the hay was sufficiently coarse to provide a true roughage or scratch factor within the rumen, not simply an energy-dilution effect. In that research, inclusion of 16% hay resulted in greater ruminal pH versus 8% hay, but hay percentage did not affect LA; conversely, hay particle size did not affect ruminal pH but did influence LA.

Galyean and Defoor (2003) reported that although roughage level in finishing diets explained 69.9% of variation in DMI of feedlot cattle, level of effective NDF, which is the NDF supplied solely by the roughage sources in the same diets, explained 93.1% of variation in DMI. Acidosis, either clinical or subacute, affects DMI (Fulton et al., 1979), and roughage level in the feedlot diet and form of that roughage can influence predisposition to acidosis through myriad mechanisms (Owens et al., 1998; Galyean and Hubbert, 2014). The most obvious way increased roughage may reduce risk of acidosis is by simple dilution of energy substrate, both within the entire rumen ecosystem and within each bite of feed. By diluting the total volume of fermentable grain with added roughage, the ratio of saliva to grain increases, improving the acid-buffering capacity from the moment feed is consumed. Calderon-Cortes and Zinn (1996) reported that feeding 16% hay resulted in greater ruminal pH versus feeding 8% hay. Rumination time, and, hence, salivary buffering, may be related to level of roughage; however, this relationship is subject to source and form of the roughage. Moore et al. (1987) reported that rumination time was greater for diets containing 10% wheat straw versus 10% cottonseed hulls or 10% alfalfa, and pH was also numerically greater for the wheat straw–containing diet; ruminal fill was greatest in the diet containing cottonseed hulls. Roughage has a greater potential to affect rumination and buffering capacity if it persists in the form of a floating fiber mat for a greater length of time. Passage rate out of the rumen is greater for alfalfa than for wheat straw when included as the roughage source in finishing diets (Moore et al., 1990; Poore et al., 1990). Increasing roughage inclusion will likely increase water intake and rumination (Owens et al., 1998), resulting in increased liquid dilution rates and greater efflux of both fermentable starch and acid, resulting in reduced acid load in the rumen (Galyean and Defoor, 2003).

Ørskov et al. (1979) reported that rumenitis and parakeratosis common in sheep fed continuously through intragastric infusion could be prevented through the physical stimulation of the rumen epithelium provided by plastic pot scrubbers inserted into the rumen. Loerch (1991) reported that placement of six 10 × 7 cm woven polypropylene pot scrubbers into the rumen of feedlot cattle fed 100% concentrate diet resulted in numerically fewer condemned livers; however, no significant differences were seen in ruminal pH or liquid dilution rate; this was attributed to the size of the items being too large to be regurgitated to stimulate rumination and salivation. These data suggest that physical stimulation of the rumen epithelium provides a benefit to maintaining the physical integrity of the ruminal epithelium independent of any buffering effect. Roughage level and form likely affect LA through both buffering and physical stimulation.

Simply replacing a starch-based energy source with an NDF-based energy source does not reduce incidence of LA. Meyer et al. (2013) replaced 25% of the corn in finishing diets based on dry-rolled corn with 25% wet distillers grains and reported no reduction in the incidence of LA. He et al. (2014) reported that replacing 30% of the grain in a rolled barley–based finishing diet with 30% distillers grains resulted in total LA increasing from 15 to 49% and severe LA increasing from 10 to 33%. Furthermore, Yang et al. (2012) replaced the dietary NDF of the basal rolled barley–based finishing diet (15% barley silage) with an equivalent percentage of NDF supplied by 25, 30, and 35% wheat dried distillers grains, removing 20% barley and either 5, 10, or all 15% of the silage and reported that total LA increased from 12% to 16, 25, and 50%, respectively, and severe LA for the 4 diets were 8, 8, 16, and 20%, respectively. The NDF provided by grain processing by-products does not appear to function similarly to NDF provided by roughage.

Grain Processing

Also germane in any discussion of the sequelae from acute and chronic acidosis is grain type and degree of grain processing. Axe et al. (1987) reported that ruminal starch fermentation of dry-rolled wheat is 94% compared with that of high-moisture sorghum grain, which is 48%, with a difference in total VFA concentration of 128 versus 103 m*M*, respectively; they also reported lower lactate concentrations for the sorghum diet versus the wheat diet. Stock et al. (1991) reported that total VFA concentration in the rumen of cattle fed a diet based on high-moisture corn versus a 50:50 blend of high-moisture corn with dry-rolled sorghum grain was 120 versus 109 m*M*.

Grain processing has as great or an even greater effect on rate and extent of ruminal starch fermentation as grain type. Kreikemeier et al. (1990) reported that rate of starch digestion in the rumen for dry-rolled wheat versus steam-rolled wheat was 21%/h versus 6%/h, a 3.5-fold increase, and Stock et al. (1991) reported that high-moisture corn had almost 2-times more rapid fermentation of starch versus dry-rolled corn. Swingle et al. (1999) reported that more extensively steam flaking corn increases ruminal starch disappearance from 82 to 91%, and Luebbe et al. (2012) reported ruminal starch digestibilities for steam-flaked corn versus dry-rolled corn of

90 versus 78%. Zinn (1990) reported a linear reduction in ruminal pH 4 h after feeding with a linear decrease in steam-flaking density; however, Ponce et al. (2013) reported no effect of steam-flaked corn bulk density on ruminal pH, total VFA concentrations, or in vitro DM digestibility.

Although grain type and degree of processing affect fermentation characteristics, there is little evidence supporting the effect of grain type and processing on prevalence of LA. Mader et al. (1991) reported no difference in prevalence of LA for cattle fed ground high-moisture corn versus dry-rolled corn; Ponce et al. (2013) reported no effect of corn flake bulk density on LA. Reinhardt et al. (1997) reported a linear increase in area of the pH curve below pH 5.0 and 5.5 with decreasing steam-flaked sorghum grain bulk density and numerically greater lactate concentrations following an intake challenge; however, there was no effect of decreasing bulk density on LA. Loerch and Fluharty (1998) reported no significant difference but a numerical decrease in condemned livers for cattle fed finishing diets containing dry-rolled corn versus whole corn. Huck et al. (1998) fed cattle finishing diets based on dry-rolled corn, high-moisture corn, or steam-flaked corn, with 10% corn silage as the sole roughage source, and reported no effect of grain processing method on prevalence of LA.

These observations suggest that, in a high-grain finishing diet, the roughage level and form have a much greater effect on LA than does grain source or degree of processing. Abundant evidence demonstrates that different grain sources and processing methods substantially alter the rate and extent of ruminal starch fermentation, and the resulting VFA and lactate concentrations, and the ruminal pH. And yet, the data reported herein suggest that the increased fermentability of some grain sources does not greatly affect incidence of LA; roughage source, form, and level have a seemingly much greater effect.

Vaccination

Vaccination of the host animal against the most common LA-associated bacteria, *F. necrophorum* and *T. pyogenes*, has been effective under controlled conditions in challenge studies, but data are equivocal in production settings. Saginala et al. (1997) reported dose-dependent increases in serum neutralizing titers and ELISA titers after vaccination of steers using a *F. necrophorum* toxoid vaccine compared with titers from control steers injected with a buffered saline, with the vaccinates demonstrating elevated titers for 6 wk after vaccination. In that same experiment, LA were experimentally induced in the steers by intraportal injection of *F. necrophorum* ssp. *necrophorum*. Whereas 100% of the control steers developed LA, only 20% of the steers given the greatest dose of vaccine antigen developed LA. Vaccinated steers that did not develop LA had 4-fold greater serum neutralization titers at wk 4 after vaccination and 3-fold greater ELISA titers versus those vaccinated steers that did develop LA. Jones et al. (2004) vaccinated steers with a bacterin-toxoid vaccine against both *F. necrophorum* and *T. pyogenes* in 2 field studies with a natural, nonexperimentally induced risk of infection. One of the experiment resulted in 50 and 63% reductions in prevalence of total and severe LA, respectively, for vaccinates versus controls (no tylosin fed), and the second study resulted in 38 and 26% reductions in prevalence of total and severe LA, respectively, for vaccinates versus controls (no tylosin fed). Checkley et al. (2005) reported that vaccination against *F. necrophorum* was effective at reducing prevalence of moderate and severe LA in animals with a low (10%) prevalence of LA but was not effective in animals with a high (30%) total prevalence of LA. Fox et al. (2009) examined vaccine effectiveness using 1,307 cattle fed in a commercial feedyard in Kansas (tylosin was not provided during the feeding period) and given either no vaccine, a vaccine containing *F. necrophorum* alone, or a vaccine containing both *F. necrophorum* and *T. pyogenes* in combination and found no effect of vaccination on prevalence of either total or severe LA; prevalence of total and severe LA was 56 and 37% in the nonvaccinates.

CONCLUSIONS

Rumen insult and damage creates a physical pathway for pathogenic bacteria to pass out of the rumen and on to the liver, where abscesses form. Although feeding tylosin continues to generally be effective for the control of LA in United States feedlot cattle, there have been recent examples of tylosin-fed cattle exhibiting unexpectedly elevated levels of total and severe LA in the high plains region of the United States Vaccination of feedlot cattle against *F. necrophorum* or other LA pathogens does not appear to be a thoroughly effective alternative means for control of LA. Even though increasing the degree of grain processing increases the rate of ruminal starch fermentation and the potential risk of acidosis, degree of grain processing does not appear to be a primary contributing factor in formation of or reduction of LA; instead, however, inclusion of physically effective roughage in the diet, in a sufficiently coarse form, and in sufficient quantity that allows development of a robust and persistent fiber mat within the rumen, appears to provide the most reliable control of LA, regardless of degree of grain processing or implementation of other methods of mitigating LA. Increasing scrutiny of animal husbandry practices suggests that further research into management practices that decrease LA would be beneficial. Because roughage is costly and difficult to manage in the feedyard, studies should focus on means to maximize the benefits of roughage by altering the timing, level, and form of roughage included in finishing diets.

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