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Use of feed additives to improve feed efficiency and growth of feedlot cattle

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Abstract. The producers must observe feed efficiency (FE) and profitability in feedlot cattle under scenarios of high production costs associated with feeding. The most efficient and persistant way to change FE is using genetic tools. However, genetic selection in cattle is slow compared to the use of feed addititves, which work to stabilize ruminal pH, induce beneficial changes in the rumen microbial population, and increase efficiency in energy and protein metabolism. The literature is extensive about antibiotics, ionophores, and non-ionophores increasing FE. Nowadays, the use of "naturals" products as growth promoters has gained great relevance, and promising results has been reported. Therefore, this study aimed to review the use of feed additives in beef cattle feeding.

Keywords: Beef cattle, growth promoters, weight gain, phytochemicals

Uso de aditivos alimentarios para mejorar la eficiencia alimenticia y el crecimiento del ganado de corral de engorde

Resumen. Los productores deben tener en cuenta la eficiencia alimenticia y la rentabilidad en ganando de engorda donde los costos de producción asociados a la alimentación son altos. La forma para hacer al ganado más eficiente y de manera persistente es la aplicación de herramientas genéticas. Sin embargo, la selección genética en el ganado es lenta en comparación al uso de adititivos en el alimento, los cuales mejoran la eficiencia alimenticia por diferente vías, tales como: estabilizando el pH ruminal, indicen cambios benéficos en la población microbiana, o mejorando la eficiencia del metabolismo de energía y proteína. En la literatura hay mucha información que señala la mejora en la eficiencia alimenticia por el uso de antibióticos inoforos y no ionoforos. Actualmente, el uso de productos naturales como promotores de crecimiento es un tema relevante, y algunos estudios han reportado resultados prometedores. Por lo tanto, el objetivo es revisar el uso de los aditivos alimenticios en la alimentación del ganado de carne.

Palabras clave: Ganado de carne, promotores de crecimiento, ganancia de peso, fitoquímicos

Introduction

With representative feed cost, producers must observe feed efficiency (FE), often measured by the ratio between average daily gain (ADG) by dry matter intake (DMI). Therefore, Weaber (2011) reported that an 1% improvement in FE represents a 3% improvement in the body weight (BW) gain. Therefore, improving feed efficiency is an important tool to reduce the cost of cattle in a feedlot and improve profitability. It also presents an opportunity to improve the sustainability of beef production. Several studies have been conducted to improve FE in animal production, and the best example occurred in the poultry industry, where FE has improved by around 250% since the 50s (Zuidhof et al. 2014). The most efficient and persistant way to change FE occurred by genetic tools. However, genetic selection in cattle is slow compared to other animal species such as poultry, due to its less reproductive

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rates and greater generation interval. Another efficient way to improve FE occurs through feed additives. Feed additives may increase nutrient use efficiency and reduce losses, resulting in more effective fermentation routes in the rumen (Tedeschi et al., 2003). The use of molecules capable of altering the ruminal fermentation process is a tool that can used to improve cattle performance, either by increasing ADG or reducing DMI without loss of weight gain, therefore, improving FE.

Most of the effective feed additives in the cattle industry works towards to stabilize ruminal pH, induce beneficial changes in the rumen microbial population, increase efficiency in energy and protein metabolism, and decrease the risk of metabolic disorders. Most feed additives used in beef cattle may be classified as ionophores, non-ionophore antibiotics, microbial, organic acids, natural plant extract, and buffers (NASEM, 2016). Therefore, this study aimed to review the use of feed additives in beef cattle diets.

Ionophores

Ionophores are an antibiotic that selectively depresses or inhibits the growth of specific rumen microorganisms. Its molecules have chemical structures that can entrap cations, usually sodium (Na^+), which can attach to the lipid bilayer of the cell membrane of ruminal gram-positive bacteria and protozoa, facilitating the net exchange of intracellular potassium (K^+) for extracellular protons and Na^+ across the membrane (Chow et al., 1994). This process forces gram-positive microorganisms to expel protons and Na^+ at the expense of adenosine triphosphate (ATP), causing a depletion in its energy reserve, impaired cell division, and likely death of the microorganism (Russell and Strobel, 1989).

The effect of ionophores in the rumen is related to a change microbial ecosystem, in which gram-negative microorganisms are favored. This bacteria group is less sensitive to the action of ionophores because of its outer membrane. As a result, the main effects o ionophores are to decrease the molar proportion of methane and increase the molar proportion of propionate in the rumen (Bergen and Bates, 1984; Russell and Strobel, 1989).

Changes in fermentation dynamics in the rumen may improve the efficiency of energy capture and the utilization of dietary N. Ionophores also have an additional effect on preventing bloat, subclinical acidosis, and coccidiosis (McGuffey et al., 2001; Ribeiro et al., 2019). There are some suggestions that using ionophores in cattle diet may present a hazard to human health due to the potential of bacteria becoming resistant to this antibiotic (Russell and Houlihan, 2003). However, ionophores are not used in human therapy because of their narrow therapeutic index. In addition, there is no genetic encoded resistance to their biophysical mechanism of action, and there is rapid cell death (Russell and Houlihan, 2003). The main ionophores used in cattle diets are monensin sodium, lasalocid, salinomycin, narasin, lilimycin, and semduramycin.

Monensin

Monensin is a carboxylic polyether ionophore (Haney and Hoehn, 1967) that selectively inhibits gram-positive bacterias, which may change ruminant metabolism by increasing efficiency of energy metabolism, improving nitrogen metabolism, and reducing the risk of bloat and lactic acidosis (Schelling, 1984; Duffield et al., 2012). Perry et al. (1976) and Ellis et al. (2012), reported that monensin was able increase positive metabolic pathways of ruminal fermentation, improving the energetic efficiencies by decreasing loses in inefficient pathways such as decrease methane production, increase the molar proportion of propionate, and decrease butyrate. Moreover, sodic monensin decreases the deamination and absorption of ammonia and methane production (Russel and Strobel, 1989), and increase the flux of dietary protein into the small intestine (Bergen and Bates, 1984).

Monensin is a feed additive that often reduces DMI with no negative impact on ADG in feedlot cattle (Duffield et al., 2012). Furthermore, it may prevent digestive disorders like acidosis (Owens et al., 1998), and be used as coccidiostat for ruminants to prevent clinical coccidiosis (Chartier and Paraud, 2012). Ribeiro et al. (2019), reported that lambs fed with diets containing monensin had less coccidia oocyst discharge compared to ewes that were supplemented with thyme essential oil (EO), or not supplemeted with any feed additive.

Narasin

Narasin is an ionophore antibiotic produced by bacteria of the genus Streptomyces aureofaciens, chemically characterized by the formula $C_{43}H_{72}O_{11}$ and molecular weight of 765 g/mol (Berg and Hamill, 1978). These same authors stated that the molecule has a solubility in alcohol, acetone, chloroform and ethyl acetate, however, it is not soluble in water (Berg and Hamill, 1978). Narasin was primarily used to prevent coccidiosis in poultry (Jeffers et al., 1988), and as growth promoter in swine (Wuethrich et al., 1998; Arkfeld, et al., 2015). Similar to monensin, narasin is effective in reducing gram-positive bacteria and fungi population (Berg and Hamill 1978). However, unlike monensin, narasin has demonstrated to not negativelly affect DMI, and increased ADG in ruminants fed forage-based diets (Silva et al., 2015; Polizel et al., 2017; Polizel et al., 2018; Limede et al., 2021). However, there is a limited amount of information on the effects of including narasin as a feed additive on grain-based diets.

Lasalocid

Lasalocid is a polyether ionophore antibiotic obtained from strains of Streptomyces lasaliensis. Lasalocid has been used to improve BW gain and feed efficiency in ruminants (Bergen and Bates, 1984). Previous studies have evaluated the effects of the inclusion of lasalocid on beef cattle production. However, the effects were inconsistent in relation to ADG, DMI, FE, and carcass characteristcs (Andersen and Horn, 1987; Spears and Harvey, 1987; Barreras et al., 2013). A meta-analysis evaluating the effects of feeding lasalocid to beef cattle concluded that lasalocid increased ADG, feed efficiency, and final carcass weight, without affecting DMI (Golder and Lean, 2016).

Salinomycin

Salinomycin is an antimicrobial of the ionophore class produced by bacteria order of Actinomycetales, in which the vast majority are of the genus Streptomyces. Chemically, it is characterized by the form $C_{42}H_{70}O_{11}$, size 751 Daltons and containing a carboxylic acid with affinity for mono (K+, Na+ and Cs+) and divalent cations (Fe^{2+}, Ca^{2+} and Mg^{2+}) (Versini et al., 2018). According to the same authors, this molecule has a similar mechanism of action to other ionophores through ionic permeability in the membranes of these bacteria, acting on gram-positive bacteria due to the physical characterization of the cell membrane (Versini et al., 2018). Zinn (1986) observed that salinomycin improves growth-performance of steers fed diets with different roughage levels. However, literature about the use of salinomycin in beef cattle diets is still restricted.

Non-ionophore antibiotics

Virginiamycin

Virginiamycin is a non-ionophore antibiotic produced from a specific strain of Streptomyces virginiae. It penetrates on cell wall of gram-positive bacteria, binding to ribosome subunits in the cytoplasm, consequently inhibiting the formation of peptide bonds during protein synthesis (Cocito, 1979; Cocito and Chinali, 1985; Di Giambattista et al., 1989). Metabolic processes are disrupted in the microorganism, resulting in inhibition of multiplication, and leanding to an eventual cell death. An important ruminal microorganism that is inhibited by virginiamycin is Fusobacterium necrophorum, an etiologic agent of liver abscess in confined cattle (Nagaraja et al., 1997). Virginiamycin is active against Streptococcus bovis and Lactobacillus ruminis, preventing the rise lactic acid in the rumen. Virginiamycin increases ADG in 4-8%, FE in 5-10%, and decreases liver abscesses compared to cattle fed no feed additive in feedlot (De Araújo et al., 2016).

Microbial Additives

In recent years, people has demanded for the use of technologys to improve animals health and production without the use of antibiotics (Benchaar et al., 2006). Therefore, the use of alternative feed additives is growing, specifically, additives that may be considered more "natural" by consumers and regulatory organs (Benchaar et al., 2006; OJEU, 2003). The use of direct-fed microbial (DFM) such as yeasts and probiotics can stimulate the growth of cellulolytic bacteria (Chaucheyras-Durand et al., 2016) and reduce the lactate availability (McCann et al., 2017). Direct-fed microbial are microorganisms that have been used in livestock production for about 30 years, they were primarily used in calves to accelerate the establishment of the entire intestinal flora to increase feed digestibility and gut health (McAllister et al., 2011). In recent years it has increased the number of studies that used DMF as feed additive to adult ruminants aiming to increase animal performance, milk efficiency, and feed efficiency (McAllister et al., 2011).

One of the most common microorganisms to be fed as DFM, are yeasts products. *Saccharomyces cerevisiae* is the most common yeast used to manipulate ruminal microorganism and fermentation patterns. Most of the proposed studies have possibilities of these microorganisms to establishment a population of microorganisms that may increase fiber digestion on rumen (McAllister et al., 2011). Another possible action of DFM is the manipulation of the intestinal flora, but only few studies have been conducted to specify the impact of these microorganisms on the absorption of nutrients, or immune response in the intestines. Emmanuel et al. (2007) reported an increase in acute-phase inflammatory protein concentrations when steers fed grain-based diets were supplemented with *E. faecium* and *S. cerevisiae.*

However, further studies are needed to elucidate the possible actions of yeasts in stimulating the immune response in ruminants.

Callaway and Martin, (1997) reported that an aqueous stratum of S cerevisiae stimulated the growth and activity of lactate-using bacteria. The cause of this stimulus seems to be the great content of dicapoxylic acid, mainly malic acid in yeast, which is an intermediary for the transformation of lactate in propionate. Moreover, yeast supplementation can also stimulate a "hydrogeniotropic" bacterium ability to use H2 for acetate production in vitro (Chaucheyras-Durand et al., 1995). These bacteria inefficiently use H2 to produce acetate. In a co-culture of acetogenic and methanogenic bacteria without addition of yeast, 19% of the H2 was used for the production of acetate and 79% for the production of methane (Chaucheyras-Durand et al., 1995). In yeasts, 70% of the H2 was used for the production of acetate, indicating that acetogenic bacteria were more efficient in the use of H2 (Chaucheyras-Durand et al., 1995).

Yeast-based products can also stimulate the growth of fibrolytic bacteria that may prevent sub-acute rumen acidosis (Chaucheyras - Durand et al. 2008). Subacute rumen acidosis is characterized by repeated periods of low rumen pH, which decreased fiber digestion and absorption capacity of the ruminal epithelium (Oetzel, 2017). Callaway and Martin (1997) reported that yeast cultures stimulated the growth of two lactic acid-using bacteria, S. ruminantium and M. elsdenii, in vitro. Thus, yeasts can help to decrease lactic acid concentration, preventing sub-clinical acidosis in animals grain-based diets.

Natural plant extract

Ionophores are one of the most used feed additives for ruminants in Brazil (Oliveira and Millen, 2014), however, the use of monensin as growth promoter was banned in the European Union (OJEU, 2003), then it is necessary to find other substitutes from monensin, if it is also prohibited in others countries. One alternative has been the use of EO that are aromatic compounds extracted from plants, used as protectants against microbial infection and insect predation, but they can be used for various purposes.

As previously discussed, there is a great consumer demand by use more "natural" products. Therefore, there has been increased interest in evaluating alternatives to modulate ruminal fermentation, including the use of organic acids and plant extracts (Calsamiglia et al., 2006; Ribeiro et al., 2019; Ribeiro et al., 2020). Essential oils may be used as an alternative feed additive in ruminant nutrition since they have antimicrobial, antifungal, antiviral, antiparasitic, insecticidal, antiprotozoal and antioxidant effects because present in its composition compounds as limonene, α-pinene, β-carophylenne, p-cymene, α-humulene, and others (Burt, 2004; Cowan, 1999). The Brazilian red pepper (Schinus terebinthifolius Raddi, Anacardiaceae) is an example the EO that exhibits antifungal properties (Johann et al., 2010), antimicrobial activity (Lima et al., 2006) and the ability to change ruminal fermentative parameters in vitro and in vivo (Araújo, 2010; Faleiro Neto, 2015).

Another example is the thyme EO that was able to change the rumen microbial population (Cristani et al., 2007; Ultee et al., 2002; Juven et al., 1994), and decrease molar proportion of acetate, the acetate to propionate (Ac:Prop) ratio and increase the molar proportion of propionate in cattle fed grain-based diets (Vakili et al., 2013). Based on these characteristics, the potential of thyme EO as rumen manipulators has been extensively studied *in vitro* (Castillejos et al., 2008; Chaves et al., 2008). Khorrami et al. (2015) observed that thyme EO increases ruminal concentration of propionate and decreases Ac:Prop ratio compared to control (no feed additive) in cattle fed a 30% of forage diet.

There are several plants and compounds that has been associated with potential improve on rumen fermentation and animal performance, such as thyme, cloves, rosemary, cilantro, garlic, ginger, eucalyptus, oregano, mastic, lemon grass, lemon balm, pepper, etc. However, the use of OE as additive has been shown results extremely variable. Thus, further studies are needed to consolidate its use as additive for ruminants.

Buffers and alkalizers

Lactic acid accumulation in the rumen is a key process in ruminal acidosis (Huber, 1986), mainly because a stronger pKa (3.8) this acid. Studies had been carried out to assess the effect of buffers on acidosis (Staples et al., 1989; Calsamiglia et al., 2012). The most common buffers and alkalizers used as additive for cattle include magnesium oxide, sodium carbonate and potassium carbonate (Staples et al., 1989). Rogers and Davis (1982) reported the beneficial effect of buffers in clinical acidosis, where the percentage of buffers on diet was around 5% (Rogers and Davis, 1982). Adding 2.5 to 5% of sodium bicarbonate increased ruminal pH, without changes in diet digestibility (Okeke et al., 1983).

In smaller dosage, the response is more evident in the beginning of supplementation, which after 4 weeks the buffer effect tend to be limited (Zinn, 1991; Russell et al., 1980). In addition, the use of buffers as additive has been shown little effect in subclinical acidosis (NASEM, 2016). A lack of consistent results of buffer use as feed additive and a high price of its inclusion on diet has been a limiting factor for buffers used as feed additive for beef cattle.

Conclusion

Overall, there are several feed additives capable to increase feed efficiency, either by increasing ADG or decreasing DMI without changes in BW gain. The literature is extensive about antibiotics, ionophores, and non-ionophores increasing feed efficiency. However, there are a great demand for the use of "naturals" products, in which promising results has been reported from microbial, natural plant extract, and buffers additives. However, more research are needed in regard to the use of these feed additives in order to to clarify the mode of action of each feed additive and to be able to use them efficiently in different practical situations.

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