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Effect of trace minerals and starch on digestibility and rumen fermentation in diets for dairy heifers[1]

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ABSTRACT

The objective of this study was to evaluate the effect of different forms of trace minerals (TM) and the use of different starch levels in dairy heifer diets on rumen fermentation and digestibility. Eight rumen cannulated dairy heifers (15.4 ± 0.8 mo of age and 438.31 ± 18.08 kg of body weight) were subjected to a split-plot, 4 × 4 Latin square design with 19-d periods: 15 d of adaptation and 4 d of sampling. The whole-plot factor was type of TM; organic as proteinates (OTM) or inorganic sulfates (ITM), and the subplot was starch level (3.54, 12.95, 22.25, and 31.73%). Total collection of feces and urine was completed on d 15 to 19 to determine digestibility and TM excretion. Rumen contents were sampled on d 18 to 19 at 0, 1, 2, 4, 8, 12, 16, 20, and 22 h after feeding to measure pH and volatile fatty acid (VFA) concentrations. Plasma samples were collected to evaluate TM concentrations and enzymatic activity for ceruloplasmin, glutathione peroxidase, and superoxide dismutase. Starch level affected pH, individual VFA concentrations, and nutrient excretion. Trace mineral intake was lower for OTM compared with ITM. No effect of TM form on dry matter digestibility was detected, but as level of starch increased, diet dry matter digestibility increased. Rumen pH was lower for diets with OTM, which is consistent with higher total VFA production and butyrate proportion observed for heifers fed OTM diets. These variables may be explained by the higher bioavailability of OTM and faster utilization and fermentation by rumen microorganisms. Heifers that consumed ITM had higher moisture in feces and higher urine excretion, which increased total manure production. Total excretion of TM was not different by treatment. Blood plasma mineral concentration was not different between treatments except for Mn, which was higher for OTM. Enzymatic activity was not affected by treatments. Mineral intake was reduced and blood mineral levels were not different, suggesting enhanced absorption of OTM compared with ITM. In conclusion, based on rumen pH, VFA production, and plasma TM concentration, OTM may be more ruminally bioavailable and absorbed to a greater extent than ITM. Also, TM form affected fecal moisture and urine excretion, suggesting that ITM may stimulate water intake.
Key words: heifer, trace mineral, starch

INTRODUCTION

Finding strategies to raise dairy heifers economically and efficiently is an important issue for dairy farms. Dairy heifers are often fed a diet based on high levels of lower quality forages. However, diets with higher nutrient density and higher digestibility are known to improve feed efficiency. Thus, heifers decrease the energy used for digestion and enhance the energy used for growth when fed highly digestible diets (Zanton and Heinrichs, 2007). Although this practice is commonly used both in research and on commercial farms, it still generates some concern. The high proportion of concentrates in nutrient-dense diets could lead to low ruminal pH due to rapid fermentation in the rumen. Also, high concentrations of starch in the diet can reduce fiber digestion (Piwonka et al., 1994). Studies have reported normal growth and no effect on rumen health (Hoffman et al., 2007; Lascano et al., 2009) with more digestible, higher concentrate diets fed to heifers. Offering high-starch diets 60 d before breeding can have a positive effect on puberty, with heifers presenting estrus 24 to 22 d earlier compared with heifers fed low-starch diets in trials designed for ADG of 0.9 kg/d (Zanton and Heinrichs, 2007). At the same time, with high-starch diets heifers were 31 kg lighter than with low-starch diets (Ciccioli et al., 2005). Studies have reported that a large proportion of concentrate in the diet produces higher levels of VFA, which could saturate epithelial cells in the rumen wall and decrease the absorption rate of nutrients. This situation occurs because the majority of the processes in the cell are regulated and limited by enzymes that require micronutrients such as vitamins

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and trace minerals (**TM**) for their function (Storm et al., 2012). When the availability of these micronutrients is limited, the body cells show a low performance and metabolism.

Trace minerals such as Zn, Mn, Cu, and Co are required for structural proteins, enzymes, coenzymes, and cellular proteins and participate in many enzymatic processes in the rumen (Durand and Kawashima, 1980). This produces changes in the ruminal environment, affecting the production of VFA, digestibility of fiber, and digestion of feed. In vitro, some TM can depress cellulose digestion depending on the added level (Hubbert et al., 1958). In the same way, they could modify microbial populations and metabolic pathways in the rumen. Studies have reported that cellulose digestion decreases due to TM deficiencies at high levels of starch (Summers et al., 1957). This can occur because fast-growing bacteria (present in cattle fed high-grain rations) increase the microbial TM requirement when they are degrading starch and there is not enough TM to be used by slow-growing bacteria that are cellulose digesters (Summers et al., 1957). Studies show when levels of Mo or Co are low in the diet, fiber digestibility decreases (Durand and Kawashima, 1980; Tiffany and Spears, 2005). After supplementation of Cu and Co in ruminants fed a low TM diet, fiber digestibility and cellulose degradation increased. Supplementation with TM can also modify the molar proportions of VFA (Underwood and Suttle, 1999). In diets deficient in Se, the ruminal molar proportion of isovaleric acid increased after adding Se to the diet (Durand and Kawashima, 1980). This situation was explained by increased activity of seleno-enzymes (Durand and Kawashima, 1980). Information is limited about how the form of TM (inorganic or organic form) affects these ruminal processes.

Considering TM blood concentration, studies suggest that organic minerals are better absorbed than the inorganic forms (Spears, 1996). Also, organic TM (**OTM**) are more available for metabolic processes because they are more similar to the natural forms of presentation in the body (organic complexes rather than free inorganic ions). The organic mineral form avoids the formation of mineral complexes (e.g., thiomolybdates) or associations with other dietary components that reduce TM absorption and availability for metabolic functions (Durand and Kawashima, 1980). Additionally, due to the increased bioavailability of organic minerals, the amount supplied in the diet can be reduced, decreasing excretion and lessening the potential for environmental damage.

It has been shown that pH can modify the solubility of TM. Organic forms of Zn, Mn, and Cu are more soluble when pH decreases, increasing absorption and availability in the small intestine. Microorganisms can use both soluble and insoluble forms of elements in the rumen for bacterial metabolism (Cao et al., 2000). It is necessary to determine the specific functions of TM in the ruminal environment and how they affect microbial metabolic pathways. The aim of this study was to evaluate starch utilization and effect of TM on the rumen using different concentrations of starch and supplementing with 2 forms of TM in precision-fed (limit fed) dairy heifers. Thus, this study evaluated total-tract nutrient utilization, the ruminal environment, digestibility parameters, and TM total-tract absorption and bioavailability.

MATERIALS AND METHODS

Animals, Treatments, and Experimental Design

All procedures involving the use of animals were approved by the Pennsylvania State University Institutional Animal Care and Use Committee (#42881). Eight Holstein heifers (15.4 ± 0.8 mo of age and 438.31 ± 18.08 kg of BW) fitted with a 10-cm rumen cannula (Bar Diamond, Parma, ID) were used in a split-plot, 4 × 4 Latin square design with 4 heifers in each plot, 19-d periods including 15 d of adaptation and 4 d of sampling. The whole-plot factor was type of TM supplemented (inorganic trace mineral ITM as sulfates and organic trace mineral OTM as proteinates and yeast): Bioplex Cu, Mn, Zn, and Sel-Plex (Alltech Inc., Nicholasville, KY). The subplot was level of starch in the diet (3.54, 12.95, 22.25, and 31.73% DM). Heifers were kept in tie-stalls 35 d before the experiment (pretrial adaptation period to adapt heifers to the facility and management as well as to recover from the cannulation surgery) and then were randomly assigned to treatments. Heifers were weighed weekly, and BW was determined by the average of 2 measurements taken on the same day. The amount of TMR offered during the experiment was adjusted weekly based on BW to allow an average of 0.8 to 0.9 kg/d of ADG (Lascano and Heinrichs, 2011). Heifers were housed in individual tie-stalls in a mechanically ventilated barn. Heifers had free access to water and intake was recorded during sampling days with volume flow meters (Sensus Metering Systems, Uniontown, PA). The animals were released for exercise 3 h/d in a paved pen on nonsampling days.

Diets

Rations were fed once daily as TMR, and predicted DMI was calculated based on energy intake with diets