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Lactose in ruminants feeding: A review

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ABSTRACT

Lactose is a disaccharide and as such it has to be broken down by the enzyme lactase to its constituent glucose and galactose before absorption in the small intestine and utilization by the body can occur. Newborn mammals are well endowed with lactase but production of the enzyme falls off rapidly after weaning, so that adult animals are able to digest only small amounts of lactose. Lactose, the major carbohydrate of milk, controls milk volume by maintaining its osmolarity. Therefore, the rate of lactose synthesis in the epithelial cells of the mammary gland serves as a major factor influencing milk volume. Glucose is the main precursor of lactose synthesis in mammary gland epithelial cells. However, a lactating mammary gland cannot synthesize glucose from other precursors due to the absence of glucose-6- phosphatase and so is dependent on the blood supply for its glucose requirement. However, objective of this review discussing importance lactose and its effect on fertility, feed intake, ketone bodies, nutrient digestibility.

Key word: Ruminant, lactose, Galactose, intestine, milk, mammary gland.

INTRODUCTION

Typical bulk cow's milk contains 37g fat, 33g protein and 47g lactose, that lactose contributes nearly one-third of the total energy supplied by liquid milk [1]. Lactose (β-D- galactopyranosyl-(1-4)-D-glucopyranose) is a disaccharide that is mainly produced for feed uses (e.g., reducing sweetness, fortification of aroma, and free-flowing additives) or for pharmaceutical uses (e.g., lactose is one of the best carriers for tablet making) [8]. In the solid state, lactose appears as two isomeric forms, depending on the isomerization of α-or β-glucose: α-lactose (AL) and β-lactose (BL). The natural, stable crystalline form is AL monohydrate (ALM), the structure of which is well known. The molecules are strung together as sheets by hydrogen bonds between either lactose molecules or crystallized water and lactose molecules. The crystal appears as a pile of infinite, zigzagging chains of lactose molecules. The structure of BL has been partially described: the crystal results from the association of finite chains of molecules strung together by hydrogen bonds [2]. Lactose is found only in milk. It is a reducing disaccharide which on hydrolysis yields equal quantities of glucose and galactose. Since lactose has been shown to exhibit mutarotation,

it exists in both the alpha and beta form. It is formed in the mammary gland from glucose or glycogen and is not notably changed by modifications of the maternal diet, or by the level of blood sugar. The percentage of lactose in milk varies significantly for different species. Authors indicated that lactose is not absorbed as well as other carbohydrates, and causes only a slight increase in the blood sugar level [3]. Lactose is the only major carbohydrate of animal origin in the food supply of man. In the gut, it usually is hydrolyzed by 3-galactosidase (lactase) and absorbed as glucose and galactose. However, many non-Caucasians lack the enzyme lactase, and their ingestion of lactose can lead to fermentation of lactose in the lower gut with associated distension and discomfort, leading in some circumstances to diarrhea [4].

Lactose in nutrition: Lactose is a disaccharide and as such it has to be broken down by the enzyme lactase (g-galactosidase) (EC 3.2.1.23) to its constituent glucose and galactose before absorption in the small intestine and utilization by the body can occur. Newborn mammals are well endowed with lactase but production of the enzyme falls off rapidly after weaning, so that adult animals are able to digest only small amounts of lactose. When larger quantities are given the undigested lactose passes into the large intestine where it is broken down by bacterial action, the resulting organic acids may be of benefit to the animal, but the raised osmotic pressure caused by undigested lactose in the lower gut often causes bloating and diarrhea. Similar considerations apply to man and adults of many coloured races are deficient in lactase, though most Caucasian populations and some coloured races with a history of milk drinking appear to have acquired a mutant gene that maintains lactase secretion into adult life, It is probable that lactose is not an essential nutrient, even for infants, since any galactose required for the formation of cerebrosides and glycoproteins can be made in the liver from glucose. Even in young animals lactose is digested more slowly than other carbohydrates, this leads to the presence of undigested lactose in the distal part of the small intestine and favours the establishment there of a lactobacillus flora which maintains a low pH value in the intestinal contents. This low pH may be in part responsible for the effect that lactose has in enhancing the absorption of certain minerals, particularly calcium, by animals, though possibly not by infants [1].

Effects of processing: Lactose in milk is little affected by traditional heat processing procedures or during drying, though particularly severe heating or prolonged storage of products may lead to Maillard reaction with milk proteins, and in-bottle sterilization of infant milk foods may result in the isomerization of a small proportion of the lactose to lactulose (β-D-Galactopyranosyl- (1-4) - β-D-fructofuranose), the corresponding keto sugar, which is not digested in the intestine and which may cause diarrhea. Increasing awareness of possible problems arising from lactase deficiency, and hence some degree of lactose intolerance, has led to the development of procedures for the enzymic hydrolysis of lactose in UHT milk to glucose and galactose. Such milk retained its nutritional quality during storage for several weeks, but evaporation and spray drying caused loss of protein quality due to extensive Maillard reaction between the monosaccharide's and the milk proteins [1, 5].

Utilization of lactose from milk by-products: Whey contains about one-third of the solids of the milk from which it was derived and about 70% of these solids is lactose. In the past much of the whey produced has been used for feeding pigs and calves, but recently, as the amounts of whey available have increased, other outlets have been sought and whey has been shown to be a useful feed for cattle, given either as liquid whey or after causing the lactose in it to react with urea to give a feed containing lactosyl ureide, a source of non-protein nitrogen with a built-in supply of readily available carbohydrate. At the same time much effort has been devoted to finding uses for whey and its components in human nutrition [1, 5].

Importance and role of Lactose

Lactose, the major carbohydrate of milk, controls milk volume by maintaining its osmolarity. Therefore, the rate of lactose synthesis in the epithelial cells of the mammary gland serves as a major factor influencing milk volume. Glucose is the main precursor of lactose synthesis in mammary gland epithelial cells. However; a lactating mammary gland cannot synthesize glucose from other precursors due to the absence of glucose-6- phosphatase and so is dependent on the blood supply for its glucose requirement. Mammary glucose uptake, which is performed by both active and passive transport processes, is independent of the concentration of glucose and insulin in the arterial blood during lactation. It has also been suggested that the blood glucose concentration affects the rate of synthesis of milk lactose, hence milk volume by osmotic association. A negative correlation has been demonstrated between milk production and plasma glucose concentration and genetically superior cows which have high milk yields maintain a relatively low plasma glucose level. The general consensus at present is that lactose acts primarily as an osmolyte in milk, so that the effect of increasing lactose synthesis is to draw more water into the milk. Thus, the higher the synthesis of lactose, the greater the volume of milk produced. The effect of this process is to leave the total amount of other milk constituents such as proteins and solids unchanged. Therefore, although milk yield is increased, concentration of its constituents is decreased. A negative correlation has been also reported between milk yield and milk composition in sheep. This relationship applies not only to the more productive breeds when compared with the less productive breeds, but also within a flock, to those animals that produce more milk, and even to an animal producing at different levels throughout its lactation period. This relationship has been generally attributed to the fact that milk volume is determined by lactose secretion and in highly productive dairy animals the synthesis of fat and protein (and therefore total solids) does not keep up with that of lactose when high rates of milk secretion are achieved.

Lactose synthesis and milk yield show a linear positive correlation with glucose uptake in the mammary gland of goats and Therefore, higher lactose synthesis potential is accompanied by greater glucose uptake by the lactating mammary gland; however, this demand may be insufficiently satisfied by the rate of liver gluconeogenic activity leading to a fall in blood glucose concentration followed by a fall in HbG. Strong correlations between lactose yield and protein yield and milk volume (0.92 and 0.98 respectively) have been also reported in cattle by Miglior et al. (2007). Because lactose maintains the osmolarity of the milk, its rate of synthesis is the major factor influencing milk volume. This mechanism can explain the strong positive correlation between lactose yield and milk production. Very weak correlation between lactose percentage and milk production could be related to the osmotic regulator role of lactose. Higher or lower lactose production leaves the lactose percent of the milk almost unchanged but it can strongly affect milk volume. In genetically modified mice, it has been reported that deficiency of lactose synthase complex in the mammary gland induced by diminution of α-lactalbumin or β-1,4- galactosyltransferase (two parts of the lactose synthase complex) can lead to decreases in milk volume caused by decreased biosynthesis of lactose. Although the strong correlation between lactose yield and milk volume in the studied cattle can be explained by the mechanism mentioned above, the effect of this process would be to leave the total amount of other constituents such as protein and solids unchanged and therefore, milk concentration is decreased as it has been reported in mice and in dairy animals. However, we have shown in the present study that there are no strong negative correlations between lactose yield and milk concentration (total solid percentage), between lactose yield and the percentages of other constituents of milk and between milk volume and total solid content of milk. This suggests that higher lactose production is accompanied by higher milk volume production, higher protein and other solids (except fat) secretion into the milk to leave protein and total solid content and milk concentration

almost unchanged. Considering correlations between percentages and yields of the different constituents of milk, the strongest correlation was found between fat percent and its yield indicating that fat percentage of milk and not milk volume is the most important factor influencing fat yield. In the case of protein and total solid yields, the correlations between percentages and yields were very weak but correlations between yields and milk volumes were very strong, indicating that milk volume, which is determined by the level of lactose synthesis, is the most important factor affecting protein and total solid yields. [6, 7, 8, 9].

Effect lactose on fertility, feed intake, ketone bodies, nutrient digestibility

The level of water secretion into milk largely determines the fat and protein content of milk. The rate of water secretion is mostly determined by the rate of lactose synthesis, because lactose is the major factor responsible for the osmolality of milk. Several studies have investigated the relationship of lactose content with fertility. Francisco et al. (2003) concluded that lactose percentage seemed a good predictor of days to first and second postpartum ovulation [10]. Buckley et al. (2003) found that higher lactose percentage was associated with increased pregnancy rate [11]. Reksen et al. (2002) demonstrated that higher lactose percentage in first 8 wk postpartum was related to early luteal response in second-parity cows [12]. Fat to lactose ratio has been shown to be an indicator of subclinical and clinical ketosis and the most informative trait for estimation of energy balance. Lactose percentage has been found to be highly heritable (0.53) in Holstein cows from Michigan. Although there are several studies that have investigated the association of MUN and lactose with fertility, health, or energy balance traits, there are no studies in the literature that have investigated the association of MUN and lactose with longevity. Survival analysis using a Weibull proportional hazards model can offer better fit to survival data due to its ability to properly account for censored records. The model also accounts for the skewed distribution of survival data. Time-dependent variables can be used in the survival analysis to accurately model the effects of. Survival analysis has been used in numerous studies to assess the effect of various traits on functional. Because MUN concentration and lactose percentage have been associated with fertility, health, or energy balance traits, it might be expected that they indirectly influence the longevity of cows on farms [13].

Numerous studies have shown the benefits of high lactose inclusion in starter diets in terms of improved growth rates, food intakes, gut morphology, and reduced Escherichia coli populations. The benefits of high lactose inclusion may be due to the production of lactic acid from the microbial fermentation of lactose [14].

Butyrate is a ketogenic VFA as it is metabolized to BHBA during absorption across the rumen epithelium. Other studies have validated this effect on ketone bodies under varying conditions. Andersson and Lundstrom (1985) found a positive correlation between butyric acid intake from silage high in butyric acid and milk ketone bodies [15]. Likewise, Krehbiel et al. (1992) infused butyrate into the rumen and observed increases in plasma BHBA and decreases in plasma glucose concentrations. Lactose has been shown to ferment to butyrate in the rumen [16]. Recently, feeding lactose to lactating dairy cows at 0, 7, and 14% of diet DM increased the molar proportion of butyrate in the rumen (13.9, 16.3, and 18.0, respectively) without placing cows at risk for ketosis as evidenced by changes in plasma BHBA and glucose concentrations [15].

The resultant lower pH increases both gastric proteolysis and nutrient digestibility and increases the concentration of lactobacilli and consequently volatile fatty acid (VFA) in the large intestine. Lactic acid has been shown to reduce the incidence of scours and when supplied via water is reported to improve growth and food efficiency of weaner pigs. These effects may be due to a reduction in gastric pH and intestinal E. coli populations as a result of lactic acid

supplementation. Fructo-oligosaccharides belong to the carbohydrates that are not enzymatically digested in the gut, but are fermented by the microflora. Inulin, a blend of fructan chains, is known for its ability to modify the composition of the intestinal flora and its metabolic activity in the large intestine. As lactic acid and inulin act on different regions of the gastro-intestinal tract, supplementation of starter diets with both inulin and lactic acid may result in improved intestinal health along the entire length of the digestive tract [14].

Lactose has been shown to improve nutrient digestibility, increase food, reduce large intestinal pH and improve gastro-intestinal health [14, 18]. Pierce et al. (2004) found that high concentrations of lactose increased villous height and the ratio of villous height to crypt depth [18].

Dietary lactose has been reported to increase serum Ca concentration in rats and to improve Ca retention in rats and in man, apparently by increasing the intestinal absorption of Ca by the non-vitamin D-dependent pathway. In addition, consumption of lactose-containing diets has been shown *to* inhibit bone resorption in mice through a Ca-induced suppression of parathyroid hormone secretion. Thus, the present study was conducted to determine whether dietary lactose would counteract the effects of salt supplementation on Ca metabolism and bone composition in weanling rats [19].

CONCLUSION

Lactose, the major carbohydrate of milk, controls milk volume by maintaining its osmolarity. Lactose synthesis and milk yield show a linear positive correlation with glucose uptake in the mammary gland of goats and Therefore, higher lactose synthesis potential is accompanied by greater glucose uptake by the lactating mammary gland; however, this demand may be insufficiently satisfied by the rate of liver gluconeogenic activity leading to a fall in blood glucose concentration followed by a fall in HbG. There are strong correlations between lactose yield and protein yield and milk volume.

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