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Effect of dietary starch level and high rumen-undegradable protein on endocrine-metabolic status, milk yield, and milk composition in dairy cows during early and late lactation

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ABSTRACT

Diet composition defines the amount and type of nutrients absorbed by dairy cows. Endocrine-metabolic interactions can influence these parameters, and so nutrient availability for the mammary gland can significantly vary and affect milk yield and its composition. Six dairy cows in early and then late lactation received, for 28 d in a changeover design, 2 diets designed to provide, within the same stage of lactation, similar amounts of rumen fermentable material but either high starch plus sugar (HS) content or low starch plus sugar content (LS). All diets had similar dietary crude protein and calculated supply of essential amino acids. Dry matter intake within each stage of lactation was similar between groups. Milk yield was similar between groups in early lactation, whereas a higher milk yield was observed in late lactation when feeding HS. At the metabolic level, the main difference observed between the diets in both stages of lactation was lower blood glucose in cows fed LS. The lower glucose availability during consumption of LS caused substantial modifications in the circulating and postprandial pattern of metabolic hormones. Feeding LS versus HS resulted in an increase in the ratio of bovine somatotropin to insulin. This increased mobilization of lipid reserves resulted in higher blood concentrations of nonesterified fatty acids and β-hydroxybutyrate, which contributed to the higher milk fat content in both stages of lactation in the LS group. This greater recourse to body fat stores was confirmed by the greater loss of body weight during early lactation and the slower recovery of body weight in late lactation in cows fed LS. The lower insulin to glucagon ratio observed in cows fed LS in early and late lactation likely caused an increase in hepatic uptake and catabolism of amino acids, as confirmed by the higher blood urea concentrations. Despite the higher catabolism of amino acids in LS in early lactation, similar milk protein output was observed for both diets, suggesting similar availability of amino acids for peripheral tissue and mammary gland. The latter could be the result of sparing of amino acids at the gut level due to starch that escaped from the rumen, and to the balanced amino acid profile of digestible protein. This last aspect appears worthy of further research, with the aim to enhance the efficiency of protein metabolism of dairy cows, reducing environmental nitrogen pollution without affecting milk yield potential.
Key words: dairy cow, starch level, metabolism, milk composition

INTRODUCTION

The need to produce milk with a composition tailored to specific processing requirements has resulted in milk pricing based on its quality. This, in turn, has led to an increased interest in understanding the mechanisms affecting milk composition; namely, fat and protein synthesis and output, and to the mechanisms that alter the physico-chemical properties of milk, particularly the cheese-making features (Calamari et al., 2010; Bittante et al., 2012).

Besides genetic improvement (Bittante et al., 2012), studies have concentrated on those characteristics of the diet that may increase nutrient availability and the rate of nutrient utilization by the mammary gland (Petitclerc et al., 2000). In ruminants, these studies are complex, as physico-chemical characteristics and different combinations of feed can widely alter nutrient output from the rumen (Clark et al., 1992; Brito et al., 2007) and, in turn, modify the type and amount of nutrients that are absorbed and delivered by the portal-drained viscera into the bloodstream (Reynolds et al., 1994).

Several studies have examined the effects of diet on milk fat (Palmquist et al., 1993; Chilliard et al., 2007) and protein (DePeters and Cant, 1992; Firkins et al., 2006), but less attention has been placed on the endo-

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crine-metabolic influences on milk composition. In fact, the latter could play an essential role in determining milk characteristics (Hart, 1983), but through different mechanisms. These mainly depend on the stage of lactation, which manifests in wide variations in hormone concentrations throughout lactation, as a consequence of natural changes in the energy balance of the dairy cow (Vernon 1989; Bertoni et al., 1995; Blum et al., 2000).

A classic example of the effect of the endocrine system on milk characteristics is the injection of recombinant bST, one of the main hormones involved in the partitioning of nutrients in ruminants. When recombinant bST is injected into dairy cows, significant effects on milk yield (Burton et al., 1994) and composition (Bertoni et al., 1992) are observed. Insulin, another hormone important in nutrient partitioning, has been demonstrated to increase protein yield (Mackle et al., 1999) and decrease fat yield (Gaynor et al., 1995; Reynolds et al., 2001).

Knowledge of the effect of diet on the endocrine-metabolic system could aid in designing further studies to determine the efficiency of nutrient utilization for milk synthesis (Broderick, 2003; Firkins et al., 2006), which is needed to improve the sustainability of dairy production. Despite the fact that several studies have been conducted to clarify the role of nutrition on milk composition of dairy cows, few have investigated the relationship with the endocrine system and metabolism during lactation.

According to this framework, the aim of our research was to provide a comprehensive evaluation of metabolic, hormonal, and lactational responses in dairy cows in early and late lactation when fed diets with different energy content and rumen fermentability rate but with similar CP content and rumen degradability.

MATERIALS AND METHODS

Animals and Experimental Diets

The research was carried out using 6 multiparous Italian-Friesian dairy cows (age 6.3 ± 2.2 yr, 592 ± 77 kg of BW at the beginning of the trial) with average genetic merit (7,953 ± 640 kg of milk in the previous lactation). Cows were housed in an artificially lit and cooled tiestall barn at the Università Cattolica del Sacro Cuore located in the Po Valley (Piacenza, Italy). The barn was maintained under almost constant climatic (about 20°C, 60–70% relative humidity, 14 h of light and 10 h of dark) and managerial conditions (operators, similar batches of feeds). The study was performed with the same cows, starting from 30 DIM for the early-lactation phase of the study and from 190 DIM for the late-lactation phase. This study complied with Italian laws on animal experimentation (DL n. 116, 27/01/1992) and ethics.

Cows were blocked into 2 homogeneous groups of 3 cows each in both lactation stages (in early lactation, homogeneous for milk yield and characteristics; in late lactation, also for days of pregnancy). The groups received alternately, for periods of 28 d, 2 different diets in a changeover experimental design. The 4 diets (2 fed in early and 2 fed in late lactation) were based on a forage mixture of corn silage, hay (alfalfa and perennial grass), and concentrate (Table 1). Theoretical energy and protein requirements of the cows were calculated according to NRC (2001), and, combining the different feed, the diets were designed to have rumen-fermentable OM (Tamminga et al., 1994) equal to 12.2 kg/d in early and 10.3 kg/d in late lactation, but with different rates of carbohydrate fermentability. This was achieved with different contents of starch and sugars; that is, high in the high starch (**HS**) and low in the low starch (**LS**) diet (Table 1), with the aim of obtaining different ruminal production rates of propionic acid and a consequential chronic increase in circulating concentrations of insulin with HS diets (Bauman and Currie, 1980). The diets were similar in CP content (15.5% in both stages, Table 1), rumen soluble protein, and RUP. The latter was calculated according to Tamminga et al. (1994) to provide a level of available digestible protein at the intestine similar between diets within the same lactation stage; that is, 2 kg/d in early lactation and 1.5 kg/d in late lactation.

To provide the required RUP in both groups and in both stages of lactation, the proportions of corn gluten feed, linseed meal, fish meal, feather meal, nonruminant blood meal (the study was performed before the European Community's restriction on the use of animal sources in ruminant nutrition), and protected methionine and lysine were adjusted to provide a predicted AA profile of the intestinal digestible protein (rumen microbial protein plus RUP) similar to that of milk protein. In particular, total microbial protein yield was estimated according to Tamminga et al. (1994), whereas the AA composition was assumed from the literature. The AA composition of rumen microbial protein was an average of data reported by Clark et al. (1992) and Mantysaari et al. (1989); for AA composition of RUP, the feed data from Ganev et al. (1979) and Mantysaari et al. (1989) were used; for the rate of AA absorption in the gut and the rate of their availability to mammary gland for uptake and inclusion in milk protein, calculations proposed by Riis et al. (1990) were used; and for AA composition of milk protein, an average of the data reported by Alais (1984), Evans and Patterson (1985), Mantysaari et al. (1989), and Rohr and Lebzien (1991)