Small Ruminant Research xxx (2014) xxx–xxx

Contents lists available at ScienceDirect

Small Ruminant Research

journal homepage: www.elsevier.com/locate/smallrumres

Somatotropin supplementation decreases feed intake in crossbred dairy goats during the early phase of lactation

S. Thammacharoen[a,*], T. Nguyen[b], W. Suthikai[c], W. Chanchai[d], S. Chanpongsang[b], N. Chaiyabutr[a,e]

[a] Department of Physiology, Faculty of Veterinary Science, Chulalongkorn University, Bangkok 10330, Thailand
[b] Department of Animal Husbandry, Faculty of Veterinary Science, Chulalongkorn University, Bangkok 10330, Thailand
[c] Research Center for Biotechnology in Livestocks Production, Faculty of Veterinary Science, Chulalongkorn University, Bangkok 10330, Thailand
[d] Rajamongala University of Technology, Lanna, Nan, Thailand
[e] Queen Saovabha Memorial Institute, The Thai Red Cross Society, 1871 Rama IV Road, Bangkok 10330, Thailand

ARTICLE INFO

Article history:
Received 10 January 2014
Received in revised form 7 July 2014
Accepted 8 July 2014
Available online xxx

Keywords:
Growth hormone
Food intake
Dairy goat
Feed efficiency
Leptin

ABSTRACT

Recombinant bovine somatotropin (rbST) has been shown to increase milk yield in dairy goats, especially during late lactation. The galactopoietic effect of rbST appears to derive mainly from the partitioning of nutrients to the mammary gland. Previously, this effect has been shown to coincide with an increase in feed intake. To test whether rbST has concomitantly an effect on milk yield and feed intake during the early lactation period, ten crossbred dairy goats during the peri-parturition period were selected and divided into two groups of five animals each. Two consecutive injections of sesame oil or rbST were performed at day 7 and 22 post-parturition (PP-7 and PP-22). Dry matter intake (DMI), water intake (WI) and milk yield of the individual animals were measured throughout the experiment. Blood was collected daily from day 6 post-parturition (PP-6) and throughout the first rbST injection period. Milk yield from the rbST supplemented group was slightly higher than the control group during the second rbST supplementation. Supplementation with rbST decreased significantly DMI per body weight. DMI digestibility from the second rbST injection did not differ between the treatments. The concentration of plasma IGF-1, insulin and glucose increased within 24 h after rbST injection. Importantly, plasma leptin also increased after rbST supplementation and this preceded the feed intake effect of rbST supplementation. The present results suggest that rbST induces a decrease in feed intake in dairy goats during early lactation, which relates to increase in the concentration of plasma leptin and in combination with galactopoietic effects of rbST, IGF-1 and insulin.

1. Introduction

Somatotropin (ST) or growth hormone is known for its galactopoietic effect in dairy animals. Commercial rbST has been launched and used in dairy cattle as hormonal supplementation. Cows supplemented with rbST showed a significant increase in milk yield with minor changes in milk composition. The effect of rbST on milk yield appeared to come mainly from both, the partitioning of nutrients to the mammary gland and increase in the activity of the mammary gland epithelial cells (Bauman, 1992; Etherton and Bauman, 1998). In the temperate zone,

* Corresponding author. Tel.: +66 2 2189740; fax: +66 2 2520737.
E-mail address: sprueksagorn@hotmail.com (S. Thammacharoen).

http://dx.doi.org/10.1016/j.smallrumres.2014.07.005
0921-4488/

increase in milk production in dairy cattle was not associated with an increase in feed intake during short term rbST supplementation (Peel and Bauman, 1987; Tyrrell et al., 1988). However, during long term rbST supplementation, feed intake gradually increases to support the higher milk production (Peel and Bauman, 1987; Bauman, 1992). Experiments conducted in the tropical zone have revealed a similar phenomenon. Long term supplementation with rbST increased milk yield together with feed intake in both crossbred Holstein cattle and crossbred dairy goats (Polratana, 2004; Chaiyabutr et al., 2005; Chanchai et al., 2010). Interestingly, plasma leptin in dairy cattle was reduced during long term rbST supplementation (Chanchai, 2010). It is hypothesized that changes in feed intake during rbST supplementation in dairy goat are associated with changes in plasma leptin concentration. The aim of the present study was to investigate whether supplementation with rbST during high energy demand influences plasma leptin and subsequently affects feed intake. The present experiment was performed by applying the short term rbST-supplementation model, during the early lactation period in crossbred dairy goats.

2. Materials and methods

2.1. Animals and management

Ten late pregnant crossbred dairy goats weighting 29.2 ± 2.3 kg were selected and housed in an individual cage (50 cm × 150 cm × 80 cm) in a shaded barn. The temperatures of the experimental area in the morning (0900) and in the afternoon (1500) were 18.19 ± 0.65 °C and 32.38 ± 0.29° C, respectively. The percentages of relative humidity from both periods in the morning and the afternoon were 80.12 ± 1.25 and 44.50 ± 1.30%, respectively. The temperature and humidity indexes (THI) calculated from above information were 65.61 ± 0.95 and 80.75 ± 0.43, respectively (Chanchai et al., 2010). All goats had ad libitum access to water and were fed a total mixed ration (TMR) twice daily (at 0730 and 1530) to maintain a moderate body score condition at 2.5 (1–5 scale). The TMR used in the current experiment was prepared from corn silage and concentrate according to the national research council recommendation (NRC, 1981). The TMR samples were collected once a week throughout the experiment to determine dry matter (DM). The TMRs were adjusted weekly to account for the changes in DM concentration. Other TMR subsamples were kept frozen at −20 °C for later chemical analysis according to AOAC (1990) including organic matter (OM) and nitrogen (N). The neutral detergent fiber (NDF) and acid detergent fiber (ADF) were analyzed by the procedure of Van Soest et al. (1991). The TMR (percentage of DM basis) ingredients consisted of 46% of corn silage, 30% of ground corn, 20% of soybean meal, 3% of molasses and 1% of mineral mix. The DM concentration of the TMR was 41.8%. The chemical compositions of the TMR were estimated as per DM basis for OM (94.3%), CP (23.8%), NDF (33.4%), and ADF (19.9%).

The animals were divided into control ($n = 5$) and rbST supplemented groups ($n = 5$). After parturition, the individual animals were manually milked twice daily at 07.00 am and 15.00 pm. The amount of feed and water offered and refusal were recorded daily. Daily milk yield and dry matter intake (DMI) from PP-1 to PP-34 were used to calculate the efficiency for milk (FE_{milk}). The body weight from each animal was measured once per week. At day six after parturition (PP-6), blood samples were collected via the jugular vein at 09:00 for hormone analysis as a pre-treatment sample. The blood glucose was measured immediately using a glucometer (Accu-Chek Adv II, Roche diagnostic GmbH, Manheim, Germany), while the main portion of the blood sample was placed in an EDTA tube (BD Vacutainer®, BD, NJ, USA) and kept in crushed ice. The plasma sample was separated and stored at −20 °C until analysis. At day 7 after parturition (PP-7), each animal was treated either with rbST (250 mg Posilac®, Monsanto Company, MO, USA) or the vehicle (sesame oil). The dose of rbST used in the present experiment was based on a previous experiment that had been done during late lactation (Polratana, 2004). After the first rbST supplementation, blood and milk samples were collected daily with the same procedure as described until PP-21. With the same animal group, the second rbST supplementation (PP-22) was conducted to study the effect of rbST on dietary digestibility. All experimental procedures were approved in accordance with recommendations given by the ethics committee of the Faculty of Veterinary Science, Chulalongkorn University.

2.2. Determination of plasma concentration of IGF-I, insulin and leptin

The plasma concentrations of IGF-I and insulin were determined by immunometric chemiluminescent assay (IMMULITE® DPC, CA, USA). The intraassay coefficient of variation (CV) was 6.16 and 7.44%, respectively. Plasma concentration of leptin was determined using a radioimmunoassay kit specific for multi-species hormone (Linco Research, Inc., MO, USA) with 2.43% of the intraassay CV.

2.3. Measurement of dietary digestibility

DMI digestibility was measured using the total fecal collection technique. After the second rbST injection (PP-22), total fecal were daily collected and mixed for a 10 day period from PP-25 to PP-35. The subsample (about 10% of total amount) from each animal was kept under −20 °C. The fecal samples were analyzed for DM, OM, N, NDF and ADF levels as previously described. Calculation of the percentage of apparent digestibility was done by dividing the difference between the amount of nutrient in feed and fecal excretions by the amount of nutrient in feed.

2.4. Statistical analysis

All data were reported as the mean ± SEM. Because of the similarity of 2 days consecutive data of milk yield and DMI, the average of 2-days data was calculated and used in the present experiment. All data were analyzed with the repeated two-way ANOVA. The mean comparison was done with the Bonferroni and Bonferroni–Holm follow-up test (Holm, 1979). Differences were considered significant when $P < 0.05$.

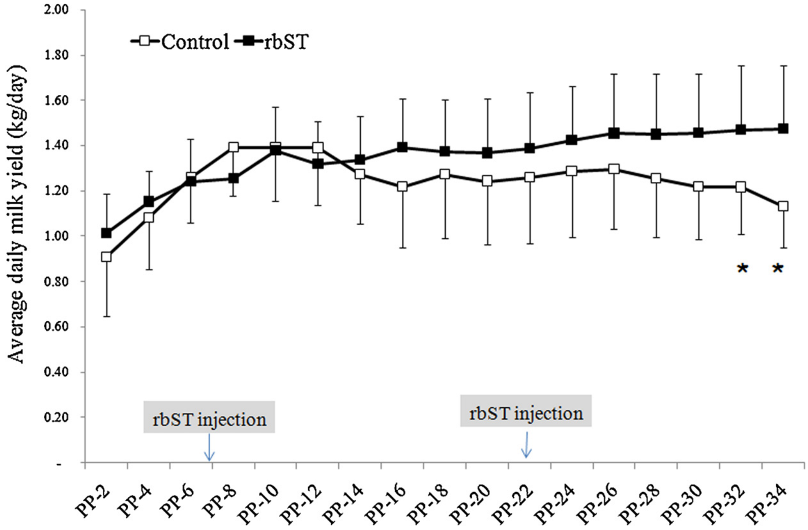

Fig. 1. Effect of rbST supplementation on daily milk yield. Asterisks show the significant effect, $P<0.05$. Recombinant bST was injected subcutaneously at day 7 post-partum (PP-7) and PP-22.

3. Results

3.1. Effect of rbST supplementation on milk yield

After parturition, the average milk yield from both groups appeared to increase from 0.96 ± 0.15 L/day on the first 2 days after parturition to 1.25 ± 0.13 L/day before rbST supplementation (PP-6: Fig. 1). The average 2-days milk yield of the last 4 days experiment (PP-32 and PP-34) from the rbST supplementation group was higher than from the control group ($t_8 = 3.00$ and 4.04, $P<0.05$).

3.2. Effect of rbST supplementation on dry matter intake, dietary digestibility, feed efficiency for milk and water intake

By the first 2 days after parturition, the DMI from both control and the rbST supplementation groups was 1.21 ± 0.20 and 1.21 ± 0.16 kg/day, respectively. Dry matter intake per body (DMI/BW) data (Fig. 2) revealed that animals from the control group maintained their DMI/BW (from PP-6 to PP34: $F_{14,56} = 0.34$, $P>0.05$), while in the rbST supplemented group DMI/BW decreased ($F_{14,56} = 2.07$, $P<0.05$). The significant decrease in DMI/BW in the rbST

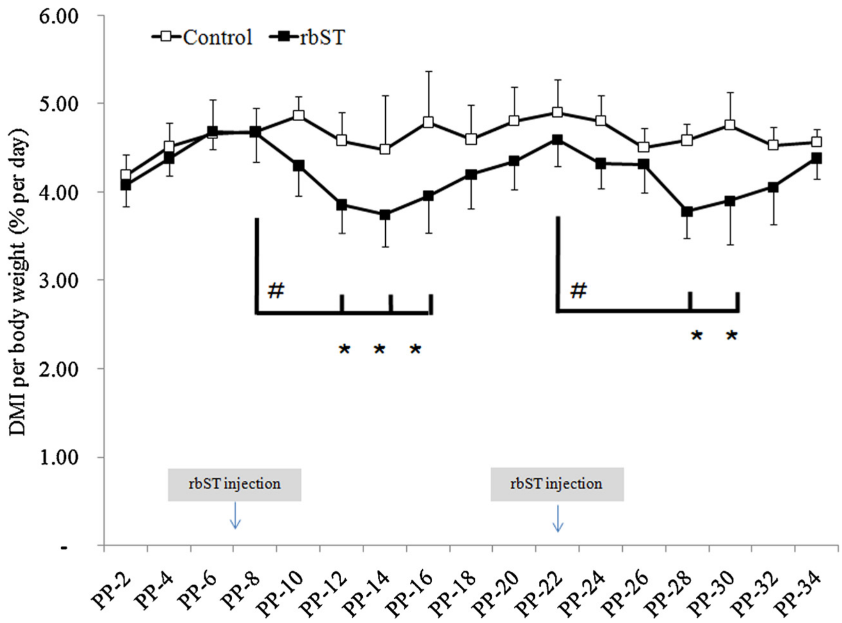

Fig. 2. Effect of rbST supplementation on dry matter intake per body weight. Recombinant bST was injected subcutaneously at day 7 post-partum (PP-7) and PP-22. Asterisks at the specific post-partum days indicate a significant difference between control and rbST supplementation groups. The pound sign over the indicator line reveals a significant decrease between pre and post rbST supplementation days, $P<0.05$.

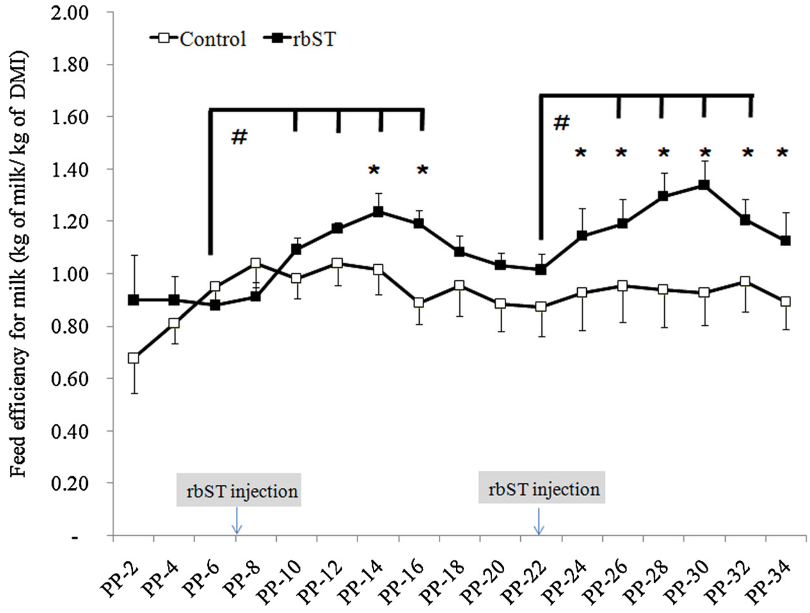

Fig. 3. The feed efficiency for milk between the control and rbST supplementation groups. Recombinant bST was injected subcutaneously at day 7 post-partum (PP-7) and PP-22. Asterisks at the specific post-partum days indicate a significant difference between control and rbST supplementation groups. The pound sign under the indicator line reveals a significant increase between pre and post rbST supplementation days, $P < 0.05$.

supplemented group was apparent from day 5 to 10 (from PP-12 to PP-16, $t_8 = 3.80$, 4.31 and 3.35, $P < 0.05$) after the first rbST injection and from day 5 to 8 (PP-28 to PP30, $t_8 = 3.74$ and 3.19, $P < 0.05$) after the second rbST injection. Likewise, DMI/BW from rbST supplemented animals was lower than from the control animals during the first rbST injection (PP-12, PP-14 and PP-16, $t_8 = 3.20$, 3.23and 3.67 respectively, $P < 0.05$) as well as from the second rbST injection (PP-28, and PP-30, $t_8 = 3.55$ and 3.78 respectively, $P < 0.05$).

During the second administration of rbST, the apparent nutrient digestibility did not differ between the rbST supplemented and control groups. The overall mean of apparent digestibility in the control and rbST supplementation groups was 77.5 ± 1.4 and $77.6 \pm 1.0\%$ for dry matter ($t_8 = 0.09$, $P > 0.05$), 79.5 ± 1.3 and $79.6 \pm 1.0\%$ for organic matter ($t_8 = 0.07$, $P > 0.05$), 77.6 ± 1.9 and $78.3 \pm 1.3\%$ for CP ($t_8 = 0.32$, $P > 0.05$), 52.8 ± 1.9 and $54.9 \pm 2.2\%$ for ADF ($t_8 = 1.25$, $P > 0.05$) and 58.0 ± 2.3 and $58.3 \pm 2.6\%$ for NDF ($t_8 = 0.09$, $P > 0.05$).

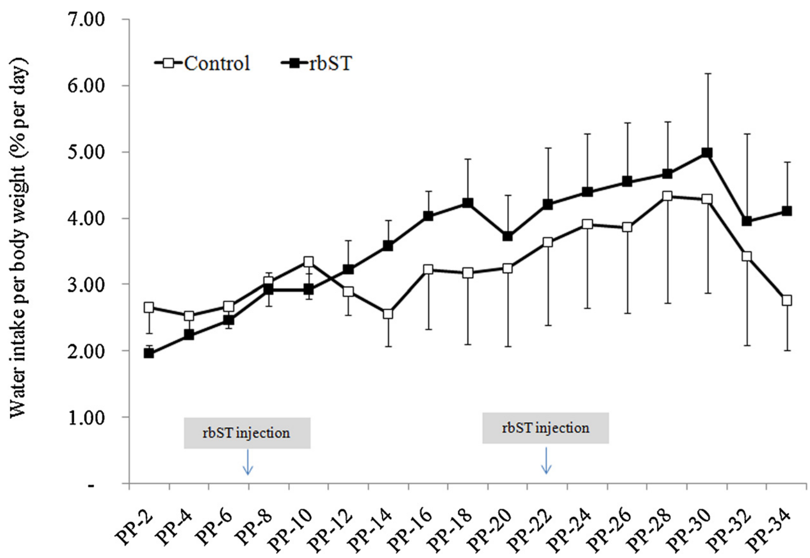

Fig. 4. Effect of rbST supplementation on water intake per body weight. Recombinant bST was injected subcutaneously at day 7 post-partum (PP-7) and PP-22.

Please cite this article in press as: Thammacharoen, S., et al., Somatotropin supplementation decreases feed intake in crossbred dairy goats during the early phase of lactation. Small Ruminant Res. (2014), http://dx.doi.org/10.1016/j.smallrumres.2014.07.005

Supplementation with rbST in dairy goats during early lactation increased FE_{milk} ($F_{14,112}=2.46$, $P<0.05$; Fig. 3). This increase became significant at PP-14 and PP-16 from the first injection ($t_8=3.45$ and 4.72 respectively, $P<0.05$) and PP-24 to PP-34 from the second injection ($t_8=3.40$, 3.72, 5.54, 6.41, 3.65 and 3.62 respectively, $P<0.05$). In the control animals, the FE_{milk} did not differ throughout the experimental period ($F_{14,56}=0.61$, $P>0.05$; Fig. 3). In the rbST supplementation group, the FE_{milk} increased periodically after both injections ($F_{14,56}=4.63$, $P<0.05$). From day 3 to 10 after the first rbST injection (PP-10 to PP-16), the FE_{milk} increased significantly from pre-injection days ($t_8=3.12$, 4.30, 5.23, 4.57 and 2.98 respectively, $P<0.05$). This significance increase in FE_{milk} was observed also after the second injection (PP-26 and PP-32, $t_8=2.58$, 4.11, 4.74 and 2.78 respectively, $P<0.05$).

During early lactation, the water intake (WI) from both groups was around 3.49 ± 0.44 L/day and the water intake per body weight (WI/BW) was around $12.28\pm1.38\%$ (Fig. 4). Throughout the experimental period, WI/BW did not differ between the 2 groups ($F_{1,112}=0.07$, $P>0.05$, Fig. 4). However, animals from both groups gradually increased their WI/BW ($F_{14,112}=2.41$, $P<0.05$, Fig. 4). However, WI/BW during the post rbST treatment period increased significantly in comparison to pre-injection period only in the rbST supplemented group (PP-6, $F_{14,56}=2.00$, $P<0.05$ and 0.89, $P>0.05$, respectively, Fig. 4).

3.3. *Effect of rbST supplementation on plasma glucose, insulin, IGF-I and leptin*

Before treatment, there were no differences between the 2 groups in plasma glucose, insulin and IGF-I concentrations (Fig. 5a–c). Twenty-four hours after the rbST injection (PP-8), plasma concentrations of IGF-I (Fig. 5a), blood glucose (Fig. 5b) and plasma insulin (Fig. 5c) were significantly higher than in the control group ($t_8=5.18$, 2.82 and 3.83 respectively, $P<0.05$).

Exogenous rbST significantly increased plasma leptin concentrations in the current experiment (Fig. 6, $F_{7,56}=2.29$, $P<0.05$). However, the concentration of plasma leptin between both groups was not significantly different at 24 h after treatment ($t_8=0.09$, $P>0.05$). Plasma leptin from the rbST supplementation group was higher than that of the control group at PP-10 and PP-16 ($t_8=3.94$ and 3.73, $P<0.05$, respectively).

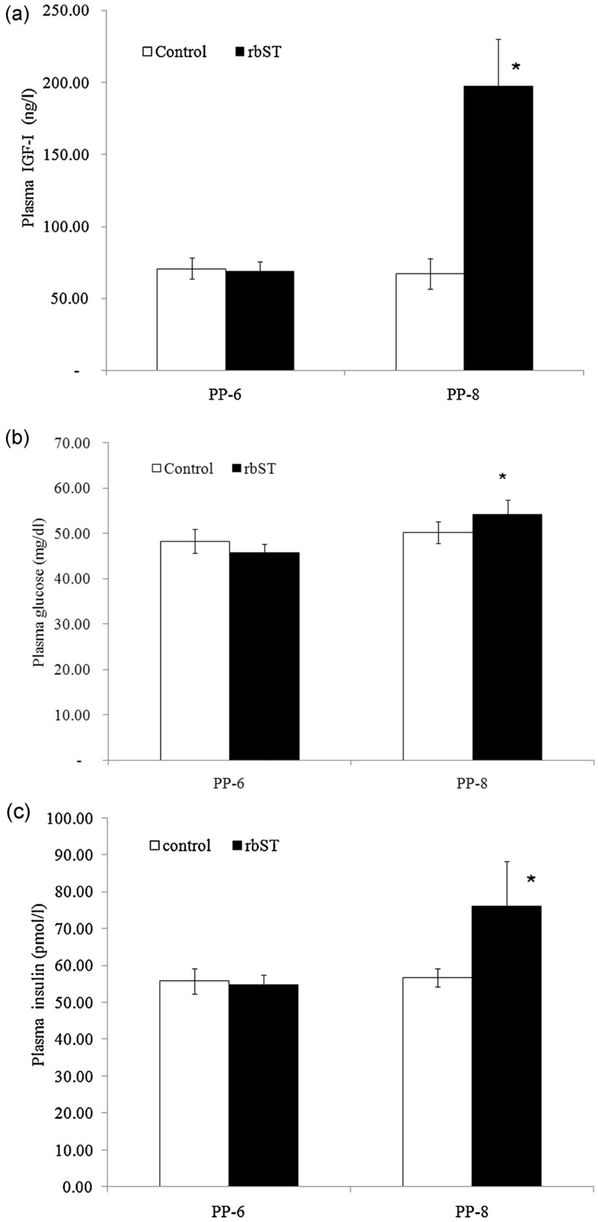

Fig. 5. The concentration of plasma IGF-I (a), blood glucose (b), and plasma insulin (c) 24 h before and after rbST supplementation. Recombinant bST was injected subcutaneously at day 7 post-partum (PP-7). Asterisks show a significantly higher concentration than the control group, $P<0.05$.

4. Discussion

The present results provided evidence that the increased plasma leptin after rbST supplementation was coupled with the feed intake effect. The compelling evidence for this conclusion was the phased decrease in DMI after short-term rbST supplementation.

It is well known that rbST produces a positive effect on milk yield in dairy animals. In the present experiment, rbST effect on milk yield was small and detected only during the last 2 weeks of the second rbST injection. This is in line with the previous results that the galactopoietic effect of rbST during the early phase of lactation is small. In spite of the small effect of rbST on milk production, the present results revealed the interesting unexpected effect of exogenous ST on feed intake. Supplementation with rbST decreased rather than increased both DMI and DMI/BW, in consistent with previous results (Polratana, 2004; Chanchai et al., 2010). The effect could be detected as early as day 5 and 6 after rbST injection (PP-12) and then returned to baseline feed intake before the next injection. Thus, our data show a close timing between rbST treatment and the effect of rbST on feed intake that faded quite rapidly (Fig. 2).

Several previous experiments suggested that rbST effect on feed intake is specie-specific and influenced partly

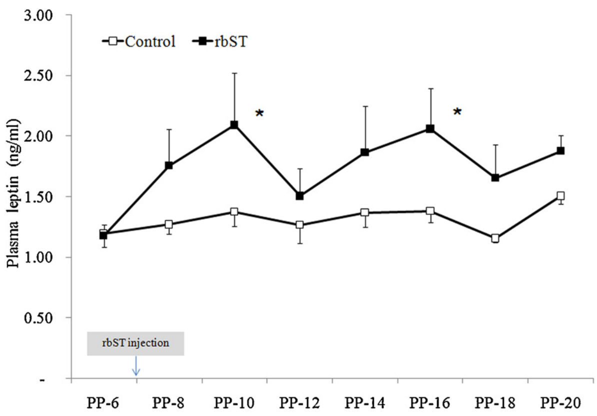

Fig. 6. Plasma concentration of leptin from the first rbST supplementation. Recombinant bST was injected subcutaneously at day 7 post-partum (PP-7). Asterisks on the specific post-partum days indicate a significant difference between the control and rbST supplementation groups, $P < 0.05$.

by metabolic status. In pigs, exogenous ST supplementation clearly decreased feed intake while increasing feed efficiency (Boyd et al., 1991). In female rats, supplementation with ST was associated with increased and unaltered feed intake coupled with increased feed efficiency. However, when feed intake was normalized with body weight, which increased after ST treatment, it turned out that ST supplementation failed to change or decreased feed intake per body weight (Roberts et al., 1994; Azain et al., 1995; Malmlöf et al., 2011). In dairy ruminants, the feed intake effect of rbST supplementation remains uncertain. Increased milk yield and feed intake after rbST supplementation have been demonstrated in some experiments (Peel and Bauman, 1987; Bauman, 1992; Polratana, 2004; Chaiyabutr et al., 2005; Chanchai et al., 2010). However, in other reports, rbST increased milk production without an effect on feed intake (Disenhaus et al., 1995; Chadio et al., 2000; Sallam et al., 2005). The data reported in the present experiment supports and extends previous information that short term rbST supplementation temporarily decreased feed intake, even during the period of energy shortage of early lactation. Taken together, it seems likely that the feed intake effect of exogenous supplementation of rbST in dairy ruminants is a chronological phenomenon. Short term supplementation (within 28 days of 2 consecutive injections) during early lactation appears to decrease feed intake, while long term supplementation increases feed intake. Since the feed intake effect in long term ST supplementation appears to be a secondary effect due to the physiological adjustment to meet the energy and nutrient requirements for higher milk synthesis, short term ST supplementation that decreases feed intake appears to be the primary ST effect. In addition, a lack of change in nutrient digestibility, in consistent with earlier reports (Cheli et al., 1998; Santos et al., 1999; Chanchai et al., 2010), suggest that rbST has negligible effect on the pre-adsorptive stage and that decreased in feed intake in the present experiment came mainly from the rbST effect of post-absorptive stage or the whole body metabolism.

Supplementation with ST increased plasma IGF-I within 24 h. The result reported in the current experiment is in line with the previous model in humans, rats and dairy animals in which ST activates IGF-I secretion mainly from the liver (Zhao et al., 1994; Disenhaus et al., 1995; Faulkner, 1999; Castigliego et al., 2009; Møller and Jørgensen, 2009). In general, somatotropin can mediate its effect through ST receptors both directly (IGF independent pathway) via the activation of tyrosine kinases (JAK/STAT pathway) and via the IGF system (IGF dependent pathway; Le Roith et al., 2001; Møller and Jørgensen, 2009). Because peripheral or central administration of IGF-I failed to alter the feed intake in both rat and sheep (Foster et al., 1991; Böni-Schnetzler et al., 1999; Lu et al., 2001; López-Menduiña et al., 2010), the decreased feed intake after rbST treatment in the present experiment was apparently not related IGF effect.

Some evidence from the transgenic mouse model and natural mutation of the ST system provided the interesting aspects of ST on feed intake. Relative to body weight, ST receptor knockout, ST antagonist transgenic mice ate more than control littermates, whereas bovine ST transgenic and IGF-I over production mice ate comparable to their control (Coschigano et al., 2003; Berryman et al., 2004, 2006; Klöting et al., 2008). The results suggest the loss function of ST increase feed intake, while the excess of ST and IGF-I failed to produce the opposing behavioral effect. Further important information revealed that mice with over expression of ST in the central nervous system which showed normal plasma ST and IGF-I were obesity and hyperphagia (Bohlooly-Y et al., 2005). On the basis of the transgenic mouse model, it seems that ST effect on feed intake could be mediated centrally via its receptor expressed in the nervous system or peripherally via its receptor expressed throughout the body. Thus, the effect of exogenous rbST on feed intake in the present experiment appeared to be an IGF independent mechanism and the effect was apparently mediated via the peripheral rather than central mechanism. The peripheral effect of exogenous ST will be discussed below.

Supplementation with rbST increased plasma glucose and insulin within 24 h. Similar evidence of rbST supplementation on plasma glucose and insulin has been demonstrated in dairy ruminant (Hodate et al., 1991; Faulkner, 1999). An increase in plasma glucose and insulin suggests that exogenous rbST may decrease insulin sensitivity, influence insulin secretion and thereby decrease glucose disposal (Bauman and Vernon, 1993; Schwartz et al., 2000; Mauras and Haymond, 2005; Møller and Jørgensen, 2009). In addition to the acute effect of rbST on IGF-I, insulin and glucose, we showed that rbST gradually increased plasma leptin concentration. Although it is difficult at this stage to speculate on the mechanism by which rbST increased plasma leptin for the present results, the current experimental condition favors the positive effect of rbST on leptin production. Increased plasma leptin that preceded the feed intake effect in the current experiment suggests that plasma leptin may be the downstream satiation factor in the current experiment. It is well documented that leptin is an anorectic hormone (Schwartz et al., 2000; Woods and Seeley, 2000). Further research is needed to determine the effect of rbST on plasma leptin concentration and DMI during middle and late lactation period in dairy goat.

5. Conclusions

The short term supplementation with rbST in crossbred dairy goats during early lactation decreased dry matter intake, slightly increased milk yield and thereby increased feed efficiency for milk production. The coupling of plasma leptin and feed intake suggested that the feed intake effect of rbST might be mediated *in part* via rbST induced increase in plasma leptin.

Conflict of interest

We have no conflict of interest.

Acknowledgement

This research was supported by grants from the Faculty of Veterinary Science, Chulalongkorn University.

References

Association of Official Analytical Chemists (AOAC), 1990. Official Method of Analysis, 15th ed. Association of Official Agricultural Chemists, Inc., Virginia.
Azain, M.J., Roberts, T.J., Martin, R.J., Kasser, T.R., 1995. Comparison of daily versus continuous administration of somatotropin on growth rate, feed intake, and body composition in intact female rats. J. Anim. Sci. 73 (4), 1019–1029.
Bauman, D.E., 1992. Bovine somatotropin: review of an emerging animal technology. J. Dairy Sci. 75 (12), 3432–3451.
Bauman, D.E., Vernon, R.G., 1993. Effects of exogenous bovine somatotropin on lactation. Annu. Rev. Nutr. 13, 437–461.
Berryman, D.E., List, E.O., Coschigano, K.T., Behar, K., Kim, J.K., Kopchick, J.J., 2004. Comparing adiposity profiles in three mouse models with altered GH signaling. Growth Horm. IGF Res. 14 (4), 309–318.
Berryman, D.E., List, E.O., Kohn, D.T., Coschigano, K.T., Seeley, R.J., Kopchick, J.J., 2006. Effect of growth hormone on susceptibility to diet-induced obesity. Endocrinology 147 (6), 2801–2808.
Bohlooly-Y, M., Olsson, B., Bruder, C.E., Lindén, D., Sjögren, K., Bjursell, M., Egecioglu, E., Svensson, L., Brodin, P., Waterton, J.C., Isaksson, O.G., Sundler, F., Ahrén, B., Ohlsson, C., Oscarsson, J., Törnell, J., 2005. Growth hormone overexpression in the central nervous system results in hyperphagia-induced obesity associated with insulin resistance and dyslipidemia. Diabetes 54 (1), 51–62.
Böni-Schnetzler, M., Hauri, C., Zapf, J., 1999. Leptin is suppressed during infusion of recombinant human insulin-like growth factor I (rhIGF I) in normal rats. Diabetologia 42 (2), 160–166.
Boyd, R.D., Bauman, D.E., Fox, D.G., Scanes, C.G., 1991. Impact of metabolism modifiers on protein accretion and protein and energy requirements of livestock. J. Anim. Sci. 69, 56–75.
Castigliego, L., Grifoni, G., Rosati, R., Iannone, G., Armani, A., Gianfaldoni, D., Guidi, A., 2009. On the alterations in serum concentration of somatotropin and insulin-like growth factor 1 in lactating cows after the treatment with a little studied recombinant bovine somatotropin. Res. Vet. Sci. 87 (1), 29–35.
Chadio, S.E., Zervas, G., Kiriakou, K., Goulas, C., Menegatos, J., 2000. Effects of recombinant bovine somatotropin administration on lactating goat. Small Rumin. Res. 35, 263–269.
Chaiyabutr, N., Thammacharoen, S., Komolvanich, S., Chanpongsang, S., 2005. Effects of long-term administration of recombinant bovine somatotropin on milk production and plasma insulin-like growth factor and insulin in crossbred Holstein cows. J. Agric. Sci. 143 (4), 311–318.
Chanchai, W., (Doctoral dissertation) 2010. Effects of Misty-fan Cooling System on the Physiological Response in Relation to Digestive Process of Lactating Crossbred Holstein Cattle Treated with Bovine Somatotropin in the Tropics. Department of Physiology, Faculty of Veterinary Science, Chulalongkorn University.
Chanchai, W., Chanpongsang, S., Chaiyabutr, N., 2010. Effects of cooling and supplemental recombinant bovine somatotropin on diet digestibility, digestion kinetics and milk production of cross-bred Holstein cattle in the tropics. J. Agric. Sci. 148 (02), 233–242.
Cheli, F., Baldi, A., Gregoretti, L., Rosi, F., Cattaneo, D., Dell'Orto, V., 1998. Changes of plasma insulin, urea, amino acids and rumen metabolites in somatotropin treated dairy cows. Amino Acids 15 (3), 187–194.
Coschigano, K.T., Holland, A.N., Riders, M.E., List, E.O., Flyvbjerg, A., Kopchick, J.J., 2003. Deletion, but not antagonism, of the mouse growth hormone receptor results in severely decreased body weights, insulin, and insulin-like growth factor I levels and increased life span. Endocrinology 144 (9), 3799–3810.
Disenhaus, C., Jammes, H., Hervieu, J., Ternois, F., Sauvant, D., 1995. Effects of recombinant bovine somatotropin on goat milk yield, composition and plasma metabolites. Small Rumin. Res. 15 (2), 139–148.
Etherton, T.D., Bauman, D.E., 1998. Biology of somatotropin in growth and lactation of domestic animals. Physiol. Rev. 78 (3), 745–761.
Faulkner, A., 1999. Changes in plasma and milk concentrations of glucose and IGF-1 in response to exogenous growth hormone in lactating goats. J. Dairy Res. 66 (2), 207–214.
Foster, L.A., Ames, N.K., Emery, R.S., 1991. Food intake and serum insulin responses to intraventricular infusions of insulin and IGF-I. Physiol. Behav. 50 (4), 745–749.
Hodate, K., Ozawa, A., Johke, T., 1991. Effect of a prolonged release formulation of recombinant bovine somatotropin on plasma concentrations of hormones and metabolites, and milk production in dairy cows. Endocrinol. Jpn. 38 (5), 527–532.
Holm, S.A., 1979. A simple sequentially-rejective multiple test procedure. Scand. J. Stat. 6, 65–70.
Klöting, N., Koch, L., Wunderlich, T., Kern, M., Ruschke, K., Krone, W., Brüning, J.C., Blüher, M., 2008. Autocrine IGF-1 action in adipocytes controls systemic IGF-1 concentrations and growth. Diabetes 57 (8), 2074–2082.
Le Roith, D., Bondy, C., Yakar, S., Liu, J.L., Butler, A., 2001. The somatomedin hypothesis: 2001. Endocr. Rev. 22 (1), 53–74.
López-Menduiña, M., Martín, A.I., Castillero, E., Villanúa, M.A., López-Calderón, A., 2010. Systemic IGF-I administration attenuates the inhibitory effect of chronic arthritis on gastrocnemius mass and decreases atrogin-1 and IGFBP-3. Am. J. Physiol. Regul. Integr. Comp. Physiol. 299 (2), R541–R551.
Lu, H., Martinez-Nieves, B., Lapanowski, K., Dunbar, J., 2001. Intracerebroventricular insulin-like growth factor-1 decreases feeding in diabetic rats. Endocrine 14 (3), 349–352.
Malmlöf, K., Fledelius, C., Johansen, T., Theodorsson, E., 2011. The anorectic response to growth hormone in obese rats is associated with an increased rate of lipid oxidation and decreased hypothalamic galanin. Physiol. Behav. 102 (5), 459–465.
Mauras, N., Haymond, M.W., 2005. Are the metabolic effects of GH and IGF-I separable? Growth Horm. IGF Res. 15 (1), 19–27.
Møller, N., Jørgensen, J.O., 2009. Effects of growth hormone on glucose, lipid, and protein metabolism in human subjects. Endocr. Rev. 30 (2), 152–177.
National Research Council (NRC), 1981. Nutrition Requirements of Goat, 2nd ed. National Academic Press, Washington, DC.
Peel, C.J., Bauman, D.E., 1987. Somatotropin and lactation. J. Dairy Sci. 70 (2), 474–486.
Polratana, K., (Master thesis) 2004. Effects of Exogenous Recombinant Bovine Somatotropin (rbST) on Mammary Function in Late Lactating Crossbred Saanens Goats. Department of Physiology, Faculty of Veterinary Science, Chulalongkorn University.
Roberts, T.J., Azain, M.J., Hausman, G.J., Martin, R.J., 1994. Interaction of insulin and somatotropin on body weight gain, feed intake, and body composition in rats. Am. J. Physiol. 267 (2 Pt 1), E293–E299.
Sallam, S.M.A., Nasser, M.E.A., Yousef, M.I., 2005. Effects of recombinant bovine somatotropin on sheep milk production, composition and some hematobiochemical components. Small Rumin. Res. 56, 165–171.
Santos, J.E., Huber, J.T., Theurer, C.B., Nussio, L.G., Nussio, C.B., Tarazon, M., Lima-Filho, R.O., 1999. Performance and nutrient digestibility by dairy cows treated with bovine somatotropin and fed diets with steam-flaked sorghum or steam-rolled corn during early lactation. J. Dairy Sci. 82 (2), 404–411.
Schwartz, M.W., Woods, S.C., Porte Jr., D., Seeley, R.J., Baskin, D.G., 2000. Central nervous system control of food intake. Nature 404, 661–671.
Tyrrell, H.F., Brown, A.C., Reynolds, P.J., Haaland, G.L., Bauman, D.E., Peel, C.J., Steinhour, W.D., 1988. Effect of bovine somatotropin on metabolism of lactating dairy cows: energy and nitrogen utilization as determined by respiration calorimetry. J. Nutr. 118 (8), 1024–1030.

Van Soest, P.J., Robertson, J.B., Lewis, B.A., 1991. Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. J. Dairy Sci. 74 (10), 3583–3597.
Woods, S.C., Seeley, R.J., 2000. Adiposity signals and the control of energy homeostasis. Nutrition 16, 894–902.
Zhao, X., McBride, B.W., Trouten-Radford, L.M., Golfman, L., Burton, J.H., 1994. Somatotropin and insulin-like growth factor-I concentrations in plasma and milk after daily or sustained-release exogenous somatotropin administrations. Domest. Anim. Endocrinol. 11 (2), 209–216.