Effects of skim milk and whey-based milk replacers on feed intake and growth of dairy calves

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ABSTRACT
The aim of this study was to provide information concerning calf performance when dairy calves are fed milk replacers (MR) in which skim milk powder is partly or completely replaced by whey products and wheat protein. A feeding experiment comprised 30 dairy bull calves. During the pre-weaning the calves received three different MRs. The main ingredients of MR1 were skim milk powder (418 g/kg dry matter), whey powder (409) and vegetable oil (163). MR2 included less skim milk powder (300) compared to MR1 including whey powder (283), vegetable oil (190), whey fractions (100), hydrolysed wheat protein (65) and wheat starch (50). MR3 did not include skim milk powder while the main ingredients were whey powder (448), whey fractions (300) vegetable oil (160) and hydrolysed wheat protein (70). Live weight gain of the MR2 calves was 14% higher compared to the MR3 calves during the pre-weaning but there were no differences when compared MR1 calves to other treatments. No treatment differences were observed in gain during post-weaning or average during the experiment. There were no differences in feed conversion among treatments. The results indicated that both skim milk powder and whey-based products were suitable energy sources in MR.

1. Introduction
Good growth performance of calves is an important aspect of dairy herd management. Colostrum and subsequently milk provide a complete diet for the neonatal calves during the initial phase of life (Tóthová et al. 2016). Whole milk would be the most natural feed for young calves, but due to its high cost, milk replacers (MRs) are commonly used (Huuskonen et al. 2011a). The main ingredients in calf MRs in Finland are skim milk powders (non-fat milk powders) and whey products. In addition vegetable oils and wheat protein are used. Whey is a highly nutritious by product of the cheese industry which can be utilized well when fed to animals in a variety of forms such as liquid whey, condensed whey, dried whey or as dried whey products (Schingoethe 1976). A typical Finnish MR comprises skim milk powder (around 400–450 g/kg dry matter [DM]), whey powder (400 g/kg DM) and vegetable oils (150–200 g/kg DM). However, the more extensive utilization of whey products is of great interest because of their lower costs compared to the skim milk powders.

In the United States very little skim milk powder is currently used in the formulation of MR, and the primary protein source in MR is whey (Lammers et al. 1998; Hill et al. 2007a, 2007b). Ultrafiltration of whey produces a product, whey protein concentrate, which has essentially the same chemical composition as skim milk powder (McDonough et al. 1976). Lammers et al. (1998) observed that when fed only MR for 6 weeks, calves receiving the MR containing 67 or 100% whey protein concentrate had a higher live weight gain (LWG) and a better feed conversion ratio compared to calves fed the MR containing 100% skim milk powder. Nevertheless, when starter concentrate was offered for ad libitum intake, LWG was highly correlated with total starter intake; no apparent effects were due to milk protein source. In these trials reported by Lammers et al. (1998), the use of whey protein concentrate as the major protein source was better than or equal to the use of skim milk powder even though the MRs were formulated to be isonitrogenous and isoenergetic. However, only few published studies have actually compared skim milk powder and whey products as ingredients of MR. Therefore, the present experiment was conducted to evaluate calf performance when calves were fed diets in which skim milk powder was partly or completely replaced by whey products and whey protein. The aim of this work was to study whether the composition of MR would (1) affect the pre-weaning performance and weaning weight of dairy bull calves, (2) impose differences in growth rate after weaning until six month of age, and (3) affect feed conversion rate during pre- and post-weaning periods.

2. Materials and methods
2.1. Animals, management and experimental design
A feeding experiment was conducted in the experimental barn of Natural Resources Institute Finland (Luke) (64°44′N, 25°15′E) starting in June 2011 and ending in December 2011. Animals were managed according to the Finnish legislation regarding the use of animals in scientific experimentation. The feeding experiment comprised in total 30 Finnish Ayrshire bull calves.
All calves were purchased from local dairy farms. In those dairy farms the calves had a colostrum feeding programme during the first two days after birth: the calves were fed six litres of colostrum per day (delivered three times per day). Thereafter, the calves were given six litre milk per day during the next days.

In the experimental barn of Natural Resources Institute Finland the calves were housed in an insulated barn in six pens (3.0 × 3.5 m; five calves in each), providing 2.1 m²/calf. The floor of the pen was 1/3 metal slats and 2/3 rubber mats. Straw was used as bedding during the pre-weaning period. The room temperature of the insulated barn varied between 11°C and 19°C. The calves were randomly allotted to pens (five calves/pen) which were then randomly allotted to three experimental treatments.

All feeding treatments included 10 calves. At the beginning of the experiment the average live weight (LW) of the calves was 53.2 ± 3.0 kg (mean ± SD) and the overall age 20 ± 2.5 days. During the whole experimental period (from 20 to 195 days of age) the calves had free access to water from an open water bowl (1 bowl/pen). The bowls were 80 mm deep, 220 mm in diameter and had a capacity of two litres.

### 2.2. Feeds and feeding

During the pre-weaning period (age 20–75 days) the calves received three different MRs (MR1, MR2 and MR3) (at a dilution of 11.9% DM) delivered by Hankkija Ltd., Hyvinkää, Finland. Ingredients, average chemical composition and calculated nutritional values of the MRs are presented in Table 1. The MR1 was a typical Finnish MR including mainly skim milk powder (418 g/kg DM), whey powder (409) and vegetable oil (163). The MR2 included 28% less skim milk powder compared to MR1 including whey fractions, hydrolysed wheat protein and wheat starch. In the MR3 skim milk powder was completely replaced by whey powder, whey fractions and hydrolysed wheat protein (Table 1).

The MR was served by a computer-controlled feeder (two pens/feeder; Stand Alone 2 Plus, Förster, Engen, Germany; programme: Kalbmanager 4.2). The feeding temperature of the MR was 37°C. The calves were allocated to treatments at 20 days of age, and from days 20 to 62 the highest possible MR allowance was 7.5 L/d. Thereafter the calves were gradually weaned from days 62 to 75. During the pre-weaning period the calves had free access to commercial pelleted calf starter, hay and grass silage (GS). The commercial starter concentrate used during pre-weaning period was delivered by Hankkija Ltd. (Hyvinkää, Finland). It comprised (g/kg DM) barley (161), wheat bran (152), wheat (130), soyabean meal (101), naked oats (100), rapeseed cake (92), molassed sugar-beet pulp (90), molasses (50), malted sprouted barley (30), wheat feed meal (30), vegetable oil mix (20), calcium carbonate (15), brewers’ yeast (10), salt (7) and vitamin, mineral and trace element premix (12).

During the post-weaning period (age 75–195 days), the calves were fed GS and hay ad libitum, but the amount of concentrate was restricted to 3 kg (air dry)/calf/d. The commercial starter concentrate used during post-weaning period was supplied by Hankkija Ltd. (Hyvinkää, Finland). It comprised (g/kg DM) barley (227), rapeseed cake (140), wheat bran (100), molassed sugar-beet pulp (80), wheat (80), rapeseed meal (58), oats (50), molasses (50), malted sprouted barley (40), wheat distillers grain feed (40), naked oats (40), wheat feed meal (30), soyabean meal (20), calcium carbonate (16), brewers’ yeast (10), vegetable oil mix (7), salt (4) and vitamin, mineral and trace element premix (8).

Forages and concentrates were offered separately from a box feeder with proportional refusals at 5% in ad libitum feeding, and the calves were fed three times per day (at 08:00, 12:00 and 18:00 h). Refused feed was collected and measured daily at 07:00 h. Daily solid feed intake was weighed penwise (i.e. average for five calves).

The GS used in the experiment was harvested from first-year stands grown in Ruukki, Finland (64°44'N, 25°15'E). The silage was prepared from primary growth of mixed Phleum pratense and Festuca pratensis stands and harvested at early stages of maturity. The silage was cut using a mower conditioner, wilted for 5 h, harvested using a precision-chop forage harvester, ensiled in bunker silos and treated with a formic-acid-based additive (AV-2 Plus, Eastman Chemical Company, Oulu, Finland, containing (per kg additive) 760 g formic acid and 55 g ammonium formate) applied at a rate of 6 L/tonne of fresh forage. The hay used in the experiment was not chopped and was prepared from mixed P. pratense and F. pratensis stands.

### 2.3. Chemical analyses

Feed samples for chemical analyses were taken twice a week and pooled over periods of four weeks. Samples were analysed for DM, ash, crude protein (CP), neutral detergent fibre (NDF), crude fibre, ether extract and silage also for fermentation quality (pH, water-soluble carbohydrates, lactic and formic acids, volatile fatty acids, soluble and ammonia N content of total N) and digestible organic matter (DOM) in DM (D value). Feed DM values were determined by oven drying. Silage DM was corrected for loss of volatiles with equations given by Huida et al. (1986). Ash was determined after ignition in a muffle furnace at 600°C for 2 h (AOAC Official Method 942.05) (AOAC 1990). The CP content of feeds was determined using a Dumas-type N analyzer (Leco FP-428; Leco Corporation, St Joseph, MI, USA) (AOAC Official Method 968.06) (AOAC 1990). NDF was determined according to Van Soest et al. (1991).
Sodium sulfite was used in NDF-detergent solution and α-amylase in case of samples containing starch. NDF is expressed without containing residual ash. Crude fibre was determined with the modified method of AOAC (AOAC Official Method 962.09) (AOAC 1990) using glass wool instead of ceramic fibre filter. Ether extract was determined by Soxtec-analyzer (AOAC Official Method 920.39) (AOAC 1990). The silage was analysed for fermentation quality by electrolymetric titration as described by Moisio and Heikonen (1989) and for D value by near-infrared spectroscopy as described by Nousiainen et al. (2004).

### 2.4. Calculations

The metabolizable energy (ME) value of the silage was calculated using equation ME (MJ/kg DM) = 16.0 (MJ/kg DM) × DOM (kg/kg DM) (MAFF 1984). For hay the ME concentration was calculated using equation ME (MJ/kg DM) = 16.9 × DOM (kg/kg DM) – 1.05 (MAFF 1984). The ME values of the concentrates and MRs were calculated as described by Schiemann et al. (1972) and MAFF (1975, 1984).

The calves were weighed on two consecutive days at the beginning of the experiment and thereafter every 14 days. The weightings were conducted always in the morning before feeding. The LWG was calculated as the difference between the means of the initial and final LW. Health parameters such as faecal consistency (normal or diarrhoea), bloat, cough and inflammations, for example pneumonia, were monitored daily as described by Huuskonen et al. (2005) and Huuskonen and Pesonen (2015). Incidences are reported as a percentage of feeding days during the pre-weaning period.

### 2.5. Statistical analysis

The statistical analyses were performed using the SAS Mixed procedure (version 9.4, SAS Institute Inc., Cary, NC). Daily feed intake was measured separately for each pen (i.e. intake for five calves). Feed and energy intake data were analysed using one-way analysis of variance with the following statistical model (1):

$$Y_{ijk} = \mu + \beta_i + \epsilon_{ijk}$$  

where \(i = 1, 2, 3\) (feeding treatment), \(k = 1, 2\) (two groups per feeding treatment). \(Y_{ijk}\) is the dependent variable of the \(k\)th group in the \(i\)th feeding treatment. \(\mu\) is the general mean and \(\beta_i\) is the effect of the \(i\)th feeding treatment. Furthermore, \(\epsilon_{ijk}\) is the residual error.

The performance variables (i.e. LW, LWG) were measured individually. The following statistical model (2) was used to analyse the performance data:

$$Y_{ijk} = \mu + \beta_i + \theta_{ij} + \epsilon_{ijk}$$  

where \(i = 1, 2, 3\) (feeding treatment), \(j = 1, 2\) (two groups per feeding treatment), \(k = 1, 2, 3, 4, 5\) (five animals per group). \(Y_{ijk}\) is the dependent variable of the \(k\)th animal in the \(i\)th feeding treatment and the \(j\)th group in the feeding treatment. \(\mu\) is the general mean and \(\beta_i\) is the effect of the \(i\)th feeding treatment. Furthermore \(\theta_{ij}\) is the effect of the \(j\)th group nested in the \(i\)th feeding treatment and \(\epsilon_{ijk}\) is the residual error. Normality of residuals was checked for each analysis using graphical methods: box-plot and scatter plot of residuals and fitted values. Differences between the feeding treatments were compared using Tukey’s t-test.

### 3. Results and discussion

The average chemical composition and calculated nutritional values of the forages and concentrates are presented in Table 2. The GS used was of good nutritional quality as indicated by the ME value as well as the CP content. The fermentation quality of the GS was good, as indicated by low pH values and low contents of ammonia N and fatty acids. The silage used was restricted fermented with high residual water-soluble carbohydrates concentration and low lactic acid concentration.

During the pre-weaning period there were no significant differences in the MR or forage intake among feeding treatments (Table 3). However, concentrate and total DM intakes of the MR2 calves were 25 and 15% higher, respectively, compared to the MR3 calves. There were no differences in concentrate or total DM intakes when compared MR1 calves to other treatments. Due to differences in the total DM intake, the energy and CP supply of the MR2 calves were 15 and 18% higher, respectively, compared to the MR3 calves during the pre-weaning period. The reasons for the increased intake of the MR2 calves are not clear. Contrary to the present study, Terosky et al. (1997) and Lammers et al. (1998) observed no differences in feed intake parameters when dried skim milk was partly or completely replaced by whey protein concentrate. Compared to the recent Finnish experimental data sets for dairy calves in similar housing environments (Huuskonen et al. 2005, 2011a; Huuskonen 2011), the average DM intake of the calves during the pre-weaning period was approximately 20% higher in the present experiment (1.71 kg DM/d) than in the recent feeding trials (1.36 kg DM/d, average for trials). The high feed intake measured in the present study probably implies a good palatability of the starter concentrate used and a good healthiness of the calves in the present experiment.

During the post-weaning period there were no significant differences in the feed intake parameters or nutrient supply.
growth rates. The absence of casein in MR3 could be one possibility because whey protein does not clot in the abomasum is irrelevant for calf protein. Nevertheless, Grobler (2008) stated that the fact that whey protein does not clot in the abomasum is irrelevant for calf digestion because whey protein is naturally digested in the small intestine without action of abomasal proteases. Therefore, it is plausible that the difference in energy and protein intakes between the MR2 and MR3 calves was the most important explanation for the higher LWG of the MR2 calves in the present experiment.

No treatment differences were observed in LWG during post-weaning period or average during the experiment (Table 4). There were no differences in feed conversion parameters among treatments during pre-weaning, post-weaning or average during the experiment. The use of different MR did not affect the incidence of diarrhea, cough or bloat (days, % of feeding days during pre-weaning period). Similarly, Stewart et al. (1974) and Lammers et al. (1998) observed no differences among treatments for calves consuming whey or skim milk proteins.

4. Conclusion
Overall, the performance results during the pre-weaning period from 0.5 to 2.5 month of age showed that, nutritionally, both

Table 3. Daily feed dry matter (DM) intakes of dairy calves fed with different MRs.

|               | MR1          | MR2          | MR3          | SEM     | p. values |
|---------------|--------------|--------------|--------------|---------|-----------|
| Pre-weaning   |              |              |              |         |           |
| MR, kg DM/d  | 0.75         | 0.74         | 0.73         | 0.013   | 0.70      |
| Concentrate, kg DM/d | 0.64<sup>a</sup> | 0.75<sup>b</sup> | 0.56<sup>b</sup> | 0.032   | 0.05      |
| Forage, kg DM/d | 0.30         | 0.36         | 0.29         | 0.014   | 0.07      |
| Total intake, kg DM/d | 1.69<sup>a</sup> | 1.85<sup>b</sup> | 1.58<sup>b</sup> | 0.036   | 0.03      |
| Metabolizable energy intake, MJ/d | 23.5<sup>a</sup> | 26.2<sup>b</sup> | 22.4<sup>b</sup> | 0.47    | 0.02      |
| CP intake, g/d | 306<sup>a</sup> | 350<sup>a</sup> | 286<sup>a</sup> | 6.9     | 0.02      |
| Post-weaning  |              |              |              |         |           |
| MR, kg DM/d  | 2.61         | 2.61         | 2.59         | 0.075   | 0.05      |
| Concentrate, kg DM/d | 1.67         | 1.75         | 1.58         | 0.076   | 0.43      |
| Forage, kg DM/d | 4.28         | 4.36         | 4.17         | 0.075   | 0.36      |
| Total intake, kg DM/d | 48.0         | 48.8         | 47.0         | 0.73    | 0.34      |
| Metabolizable energy intake, MJ/d | 374          | 755          | 725          | 12.1    | 0.36      |
| CP intake, g/d | 741          | 755          | 725          | 12.1    | 0.36      |
| Average during the experiment |              |              |              |         |           |
| MR, kg DM/d  | 0.28         | 0.28         | 0.28         | 0.005   | 0.70      |
| Concentrate, kg DM/d | 1.87<sup>a</sup> | 1.91<sup>b</sup> | 1.82<sup>a</sup> | 0.013   | 0.04      |
| Forage, kg DM/d | 1.15         | 1.22         | 1.10         | 0.050   | 0.33      |
| Total intake, kg DM/d | 3.30         | 3.41         | 3.20         | 0.039   | 0.07      |
| Metabolizable energy intake, MJ/d | 38.8<sup>a</sup> | 40.3<sup>a</sup> | 37.7<sup>b</sup> | 0.33    | 0.03      |
| CP intake, g/d | 527<sup>b</sup> | 602<sup>a</sup> | 560<sup>b</sup> | 5.7     | 0.03      |

Notes: MR1 included skim milk powder (418 g/kg DM), whey powder (409) and vegetable oil (163). MR2 included 28% less skim milk powder compared to MR1 including whey fractions, hydrolyzed wheat protein and wheat starch. In MR3 skim milk powder was completely replaced by whey powder, whey fractions and hydrolyzed wheat protein. SEM – standard error of mean. Between-diet comparisons (Tukey, P < .05): estimated means with the different letters were significantly different (P < .05).

Table 4. LWs, LWGs, feed conversion rates and disorders of dairy calves fed with different MRs.

|               | MR1          | MR2          | MR3          | SEM     | p. values |
|---------------|--------------|--------------|--------------|---------|-----------|
| LW, kg        |              |              |              |         |           |
| Initial, at the age of 20 days | 53          | 53           | 53           | 2.2     | 0.97      |
| At the end of pre-weaning | 103         | 105          | 98           | 3.0     | 0.38      |
| Final, at the age of 195 days | 211         | 210          | 203          | 5.3     | 0.57      |
| LWG, g/d      |              |              |              |         |           |
| Pre-weaning   |              |              |              |         |           |
| MR, kg/DM     | 907<sup>a</sup> | 945<sup>a</sup> | 809<sup>b</sup> | 22.6    | 0.04      |
| Post-weaning  |              |              |              |         |           |
| MR, kg/DM     | 1192         | 1154         | 1156         | 35.8    | 0.72      |
| Average during the experiment | 1085        | 1075         | 1025         | 22.2    | 0.27      |
| Feed conversion rates |              |              |              |         |           |
| kg DM/kg live weight gain |              |              |              |         |           |
| Pre-weaning   | 1.94         | 1.97         | 1.96         | 0.068   | 0.95      |
| Post-weaning  | 3.64         | 3.80         | 3.68         | 0.059   | 0.30      |
| Average       | 3.09         | 3.18         | 3.15         | 0.048   | 0.45      |
| MJ/kg live weight gain |              |              |              |         |           |
| Pre-weaning   | 27.4         | 28.3         | 28.2         | 0.95    | 0.74      |
| Post-weaning  | 41.0         | 42.6         | 41.4         | 0.739   | 0.39      |
| Average       | 36.5         | 37.8         | 37.3         | 0.63    | 0.39      |
| g crude protein/kg live weight gain |              |              |              |         |           |
| Pre-weaning   | 357          | 379          | 360          | 12.4    | 0.50      |
| Post-weaning  | 632          | 658          | 639          | 11.2    | 0.36      |
| Average       | 544          | 564          | 554          | 9.2     | 0.58      |
| Disorders during pre-weaning period, % of feeding days |              |              |              |         |           |
| Diarrhea      | 1.79         | 3.57         | 2.50         | 0.986   | 0.45      |
| Cough         | 1.49         | 2.50         | 1.43         | 0.550   | 0.30      |
| Bloat         | 0.18         | 0.18         | 0.18         | 0.179   | 1.00      |

Notes: MR1 included skim milk powder (418 g/kg DM), whey powder (409) and vegetable oil (163). MR2 included 28% less skim milk powder compared to MR1 including whey fractions, hydrolyzed wheat protein and wheat starch. In MR3 skim milk powder was completely replaced by whey powder, whey fractions and hydrolyzed wheat protein. SEM – standard error of mean. Between-diet comparisons (Tukey, P < .05): estimated means with the different letters were significantly different (P < .05).
skim milk powder and whey products were suitable energy sources in MR in the present study conditions. This demonstrated the possibility of feeding young calves a diet including MR containing whey products. The good post-weaning daily gain of the calves until 6 month of age was not compromised by the use of diets in which skim milk powder was partly or completely replaced by whey products in MR in early life.

Disclosure statement
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