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# Performance in dairy cows and calves with or without cow-calf contact on pasture

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## HIGHLIGHTS

- Pastured dairy calves with or without cow-calf contact (CCC) had similar weight gains.
- Lower milk yields in CCC cows persistent for at least three weeks after cow-calf separation.
- Inhibited milk ejection was a challenge in milking of pastured CCC cows.

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## ABSTRACT

Interest in dairy cow-calf contact (CCC) systems is growing, yet limited research had been focused on CCC in a pasture setting. Our study aimed to evaluate the performance of pastured dairy cows and calves with or without CCC through machine milk yield and composition, cow body condition score (BCS) and body weight (BW) decrease, and calf body weight gain (BWG). We also examined calf intake of concentrates, artificially reared calves' milk intake, and the health of both cows and calves. Conducted on a commercial dairy freestall farm and summer farm in Norway from May to August 2021, the study included twenty cow-calf pairs: 17 Norwegian Red (NRF) and three NRF × Holstein crossbreeds. They were divided into two treatments: cow-calf contact (CC, $n = 10$) or early separation (ES, $n = 10$), each with two groups of five cow-calf pairs. CC pairs had full CCC on pasture until 6 weeks postpartum and part-time contact in weeks 7 and 8 (weaning). ES pairs were separated 1–3 h after birth, kept on separate pastures with no contact between ES cows and calves. ES calves' received daily milk allowances of 12–14 L (weeks 0–6), reduced to 8 L (week 7) and further to 4 L (week 8). From week 9, all calves were denied access to any milk (ES) or cows (CC). During weeks 0–6, CC cows had a daily machine milk yield 23.7 kg lower/cow than ES cows. The difference was likely affected by nursing and other factors (parity and inhibited milk ejection), and persisted during weaning, with CC cows delivering 8.3 kg less/cow/day in weeks 10 and 11 postpartum. Fat and protein content in machine milk showed no significant difference, while lactose content was lower in milk from CC cows than ES cows (week 5 postpartum). CC cows had a lower BW decrease compared to ES cows (CC: 913 g/day, ES: 1415 g/day from pasture day one through week 9). ES calves had an average milk intake of 10.7 L/calf/day (weeks 0–6), and consumed more concentrates than CC calves. Calves' daily BWG did not differ between treatments in weeks 0–6 (CC: 1340 and ES: 1250 g/day) and decreased for both treatments during weaning (CC: 1050 g/day, ES: 920 g/day in weeks 6–9). Inhibited milk ejection during machine milking was a challenge in CC cows, prompting oxytocin injections to prevent mastitis. Allowing calves full CCC or providing whole milk near ad libitum can result in similar BWG and health in calves. Further research should explore strategies to enhance milk ejection in pastured CCC cows.

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## 1. Introduction

A common practice in dairy farming is to separate the calf from the dam within the first day after calving (Hansen et al., 2023; Neave et al., 2022), and keep the calves indoors during the milk-feeding period (Hötzel et al., 2017; Johnsen et al., 2021). However, different stakeholders show growing interest in cow-calf contact (CCC) systems (Sirovica et al., 2022; Vaarst et al., 2020). Surveys indicate that many consumers prefer cow and calf to be kept together (Hötzel et al., 2017; Ventura et al., 2013) and keeping cattle outdoors on pasture (Schuppli et al., 2014).

A recent survey among 1038 Norwegian dairy farmers showed that 3 % utilized CCC systems and that 15 % wanted or planned to start with such systems (Hansen et al., 2023). Furthermore, Norwegian regulations require dairy cows to be kept on pasture for at least 8- or 16-weeks during summer season, dependent on whether they are kept in freestall or tiestall barns (Lovdata FOR-2004-04-22-665, 2004). Keeping cow and calf together on pasture may be a viable option for dairy farmers, but more knowledge is needed on how CCC affects the cow and the calf in a pasture setting.

One main barrier for dairy farmers to adopt CCC systems is the expected lower profitability if the calves suckle large amounts of milk, hence decreasing milk volume for sale (Hansen et al., 2023; Meagher et al., 2019). It is obvious that dairy cows with full CCC yield less machine milk than cows without CCC. However, after the separation of cow and calf, the machine milk yields of full CCC compared to non-CCC cows kept indoors have been shown to become similar (Meagher et al., 2019; Wenker et al., 2022a).

Studies have shown that machine milk from suckled cows contains less fat than that from non-suckled cows (Barth, 2020; Johnsen et al., 2016). The effect of CCC on the contents of protein and lactose seems less clear. Whereas some studies found a higher protein (Barth, 2020; Ospina Rios et al., 2023) and lactose content (Boden and Leaver, 1994) in CCC cows' machine milk, others found no differences (Dymnicki et al., 2013). After separation from the calves, while some have found machine milk composition to become similar for suckled and non-suckled cows (Mendoza et al., 2010), others have found differences in machine milk composition to sometimes persist (Nicolao et al., 2022).

In cows having part-time CCC, cow body weight (BW) has been shown to decrease more in suckled cows compared to non-suckling cows (Bar-Peled et al., 1995), or be similar between treatments (Nicolao et al., 2022).

Studies comparing artificial milk feeding versus suckling have found higher body weight gain (BWG) in suckling calves (e.g., Fröberg et al., 2011; Wenker et al., 2022b), but in most of such studies, the artificially reared calves have been provided restricted milk allowance (e.g. Flower and Weary, 2001; Roth et al., 2009). Milk allowance has been shown to determine calves' BWG, especially during the first weeks, when an underdeveloped rumen function prevents digestion of solid feed (Khan et al., 2011). However, in a study by Krohn et al. (1999) calves that were allowed only partial CCC due to an udder net preventing suckling the first four days postpartum had higher BWG than single-housed calves with no suckling, even though they had similar milk intakes.

Farmers practicing early cow-calf separation in a study by Neave et al. (2022) were concerned about cow-calf health in CCC systems on pasture, while the CCC farmers in the same study experienced cow-calf health benefitting from CCC. A review by Beaver et al. (2019) showed that for cows' udder health, there is either no difference or better udder health in suckled compared to non-suckled cows. For calf health, an argument in favor of early separation is the minimization of infection pressure for calves (Relić et al., 2020). The review by Beaver et al. (2019) did, however, not find support for a recommendation of early cow-calf separation, based on either cow or calf health. However, most studies in the review were from indoor conditions, and as pointed out by Neave et al. (2022), there might be differences in health issues for pasture-based CCC that have not yet been determined.

Most studies examining performance and health with CCC in dairy farming are conducted indoors (e.g., Bertelsen and Jensen, 2023; Wenker et al., 2022a, 2022b). Some recent studies have examined the performance and health of CCC cows and calves on pasture (Mac et al., 2023; Nicolao et al., 2022; Ospina Rios et al., 2023). However, one study was without any treatment comparison (Mac et al., 2023), and in two others, artificial milk-fed calves were not fed milk to satiety and were not on pasture during the milk-feeding period. Limited knowledge is available on the causal relationship between CCC and performance in pasture systems. Thus, our study aimed to evaluate the performance of pastured dairy cows and calves with or without CCC through machine milk yield and composition, cow BCS and BW decrease, and calf BWG. Additionally, we aimed to describe calf intake of concentrates, artificially reared calves' milk intake, as well as cow and calf health.

We hypothesized that lower machine milk yield in suckled cows compared to non-suckled cows would not persist after weaning and separation were completed. Likewise, we hypothesized that the milk fat content in the machine milk from suckled cows would be lower compared to that from non-suckling cows but would equalize after weaning and separation. Furthermore, we hypothesized that BCS and BW would decrease less for suckled compared to non-suckled cows. For the calves, we hypothesized that calves reared in a CCC system on pasture would exhibit higher BWG compared to those fed whole milk close to ad libitum, but that this difference would disappear after weaning and separation.

## 2. Materials and methods

This study complied with the Norwegian Regulation on Animal Experimentation (Forsøksdyrforskriften, 2015) under the Norwegian Animal Welfare Act (Dyrevelferdsloven, 2009). The study was conducted from May to August 2021 on a commercial dairy farm with 80 dairy cows in central Norway and included a freestall farm (220 m above sea level) and a summer farm (17 km from the freestall farm, 580 m above sea level).

### 2.1. Study design

In a parallel-group designed study, 20 cow-calf pairs were allocated to one of four groups with each 5 cow-calf pairs according to birth date in the (non-random) order ES1, ES2, CC1, and CC2. The reason for non-random allocation is described in Chapter 2.2. All groups were let out on pasture (see details in Chapter 2.4) and the study period was 10 weeks for each group (week 0 was defined as the average calf birth week). More information about the two treatments is shown in Table 1.

The ES calves were fed whole milk heated to 40 °C from milk bars with one artificial teat per calf (Fig. 1), with feedings at 06.30AM, 10.30AM, 04.00PM, and 08.00PM in weeks 0–6, and 06.30AM and 04.00PM in weeks 7 and 8.

### 2.2. Animals

Seventeen of the cow-calf pairs included in the study were of the breed Norwegian Red (NRF), and three pairs were NRF × Holstein crossbreeds. One crossbreed pair was allocated to the CC treatment and two were allocated to the ES treatment. One of the ES crossbreed cows was excluded from the study due to clinical ketosis. The calves used in the study were born between 7th May and 14th June with a birth weight between 29.8 and 56.0 kg (average: 44.0 kg). We assigned the pairs to their groups based on calving date to minimize calf age variation in each group. Thus, it was not possible to additionally distribute the treatments evenly according to calf sex and cow parity. The difference between minimum and maximum calf age per group varied between 6 and 8 days. Many of the cows calved in May, and the summer farm pastures (580 m above sea level) were still snow-covered at that time. For this reason, in combination with a lack of grazing area for dairy cows on the freestall

**Table 1**
Description of the two treatments cow-calf contact (CC) and early separation (ES) in the study with pastured dairy cows and calves.

| Treatment | CC ($n$ = 10 pairs in two groups) | | ES ($n$ = 10 pairs in two groups) | |
|---|---|---|---|---|
| Weeks postpartum | Cow-calf contact | Suckling allowance | Cow-calf contact | Milk allowance |
| 0–3 | Whole-day | Free, except during milking | 1–3 h on calving day, then none | 12 L/calf/day (four meals) |
| 4–6 | Whole-day | Free, except during milking | None | 14 L/calf/day (four meals) |
| 7 | Partial (fence-line): 20 h/d, full contact: 4 h/d | After milking: 2 h morning, 2 h evening | None | 8 L/calf/day (two meals) |
| 8 | Partial (fence-line): 22 h/d, full contact: 2 h/d | After milking: 1 h morning, 1 h evening | None | 4 L/calf/day (two meals) |
| 9 | Total separation (audible and visible contact) | None (cows moved 120 m away) | None | None |

farm, the groups were allocated in the order ES1, ES2, CC1, and CC2. Pastures were available for ES calves on the freestall farm also in May. The number of primiparous cows in each group was two in CC1, two in CC2, one in ES1, and zero in ES2. Finally, the number of bull calves in each group was one in CC1, one in CC2, four in ES1, and two in ES2.

### 2.3. Management from birth to pasture release

Before or within three hours after calving, each cow was moved from the freestall area to an individual calving pen (14.4 $m^2$). Within the first three hours after calving, each cow was milked by a milking robot (GEA Mione, GEA Group, Düsseldorf, Germany), and all calves were offered colostrum ad libitum from a teat bottle at their first feeding. The ES calves were tubed if voluntary intake of colostrum was < 4.5 L, according to the farmers regular practice for artificially reared calves. The CC pairs were observed after birth to make sure the cows were taking care of their calves and that the calves suckled. Each CC pair stayed in the calving pen for the first three days after calving, before being temporarily moved to the freestall area where all the non-experimental cows were also present. Once the fifth calf within a CC group was three to four days old, the whole group was transported to and let out on the summer farms pasture (see more details in Chapter 2.4). The ES calves were separated from their dams within one to three hours after birth and moved to individual straw-bedded pens (1.1 $m^2$) for three days before they were temporarily moved to a group pen (35.0 $m^2$). In the group pen, the calves had ad libitum access to silage, concentrates, and water. Once the fifth calf in an ES group was three days old, the whole calf group was let out on a freestall farm pasture (see more details in Chapter 2.4).

When the cows were at the freestall farm, they were milked by the milking robot. Inside the barn, the cows were fed a total mixed ration (close to ad libitum) containing grass silage (average: 89 % of weight on dry matter basis), concentrates (average: 11 %, DRØV Orkla 80 % Kåinn, Norgesfôr, Norway), and minerals. They also had ad libitum access to water and were fed concentrates in an automat during robotic milking (DRØV Energirik, Norgesfôr, Norway). When the CC calves were in the calving pen or the freestall area, they had no access to concentrates but access to the same silage as the cows.

### 2.4. Grazing management

The ES calves were first let out on pasture paddocks of 0.12 ha per group on the freestall farm. They were let out on 18th and 28th May, at an average group calf age of 7.6 and 7.4 days for the groups ES1 and ES2, respectively. Thereafter, the ES calves and the ES cows were transported separately to the summer farm on 7th June at an average group calf age of 27.6 and 17.6 days for ES1 and ES2, respectively. The ES pairs were let out in separate pasture paddocks on the summer farm without any contact between the ES cows and their calves. It was > 130 m between them, and they could not see each other (Fig. 2). The CC pair groups were transported directly from the barn to the summer farm on 10th and 17th June at an average group calf age of 6.8 and 6.0 days for the groups CC1 and CC2, respectively. While on pasture, the cows were milked and given concentrates twice daily in a herringbone milking parlor, at 06.30AM and 05.30PM. From when they were let out on pasture and until week 9, the CC cows received an average (± SD) of 8.1 ± 2.2 kg,


**Fig. 1.** One of the calf hides with descriptions. This photo was taken with group ES1 in their pasture paddock on the farm in their second week.

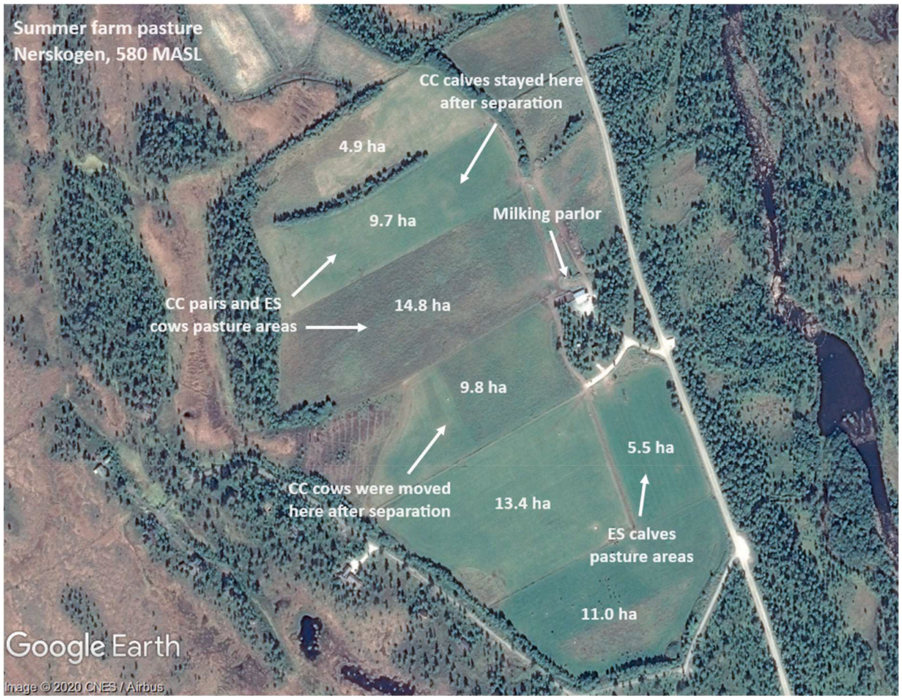


**Fig. 2.** A map of the summer farm with inserted descriptions on which areas the CC pairs, the ES cows, and the ES calves were kept on, and where the milking parlor was located.

and the ES cows received 10.0 ± 1.7 kg of concentrates/cow/day (DRØV Energirik and DRØV Genial, Norgesfôr, Norway). The concentrates were fed in the bale at the milking parlor. The amount of concentrates provided was determined by the number of days post-calving and the expected milk production for each cow.

Rotational grazing was applied for the CC pairs, the ES cows, and the ES calves. Throughout the study, the groups were regularly moved to new pasture paddocks depending on available forage, which were visually assessed by an animal nutrition researcher. Pasture paddocks was adapted to actual herbage yield and if the paddock was for cows with or without calves or only for calves. Pasture paddocks were 0.42 to 0.78 ha for each group of CC pairs, 0.45 to 0.78 ha for each ES cow group, and 0.12 ha for each ES calf group.

All cows and calves had access to pasture and water, and the CC pairs and the ES cows had access to silage throughout the study (from day one for the CC pairs and from day four for the ES cows). Each calf group had ad libitum access to concentrates (DRØV Intro, Norgesfôr, Norway) provided in a calf hide (Calf-O-Tel XL-5, VDK Products, the Netherlands) (10.9 $m^2$). Each calf hide contained straw bedding and consisted of a hutch (5.8 $m^2$) and a steel-fenced area outside the hutch (5.1 $m^2$, Fig. 1). The open gates to the calf hides were too small for the cows to enter so only the calves could use them.

The botanical composition of the pastures was estimated using the dry-weight rank method (Mannetje and Haydock, 1963), modified by Jones and Hargreaves (1979). The average botanical composition of the pastures for the CC cows and calves was 63 % timothy, 18 % other grasses, 6 % clover, and 14 % other herbs, while for the ES cows, it was 56 % timothy, 29 % other grasses, 5 % clover and 10% other herbs, and for the ES calves it was 42 % smooth meadow-grass, 2 % other grass, 4 % clover, and 52 % other herbs. Herbage samples were taken from each paddock before grazing. Dried and ground samples were analyzed by NIR spectroscopy (NIRS™ DS2500 F, FOSS, Hilleroed, Denmark) (Table 2).

Air temperature and rainfall were recorded hourly during the grazing period (Netatmo Smart Home Weather Station, Boulogne Billancourt, France). The average temperature was 14.1 °C, ranging from on average 6.6 to 22.2 °C daily. Average daily rainfall was 2.2 mm, ranging from 0.0 to 29.8 mm (53/88 days <0.5 mm and 5/88 days >10 mm).

**Table 2**
Feed value and chemical composition (NIRS) (average ± SD) of herbage samples derived from pastures before grazing in the study with the two treatments: Cow-calf contact (CC) and early separation (ES).[a]

| Variable | CC pasture | ES cows' pasture | ES calves' pasture |
|---|---|---|---|
| n (pasture paddocks) | 13 | 8 | 8 |
| $NE_L$MJ/kg of DM | 6.65 ± 0.557 | 7.03 ± 0.575 | 6.64 ± 0.382 |
| Digestability,% of DM | 76.6 ± 4.70 | 79.8 ± 4.32 | 77.1 ± 3.39 |
| PBV, g/kg of DM[b] | 25.1 ± 30.2 | 30.4 ± 35.4 | 10.0 ± 16.0 |
| AAT, g/kg of DM[c] | 86.7 ± 5.58 | 90.3 ± 5.89 | 86.4 ± 3.80 |
| Crude protein,% of DM | 17.5 ± 3.82 | 18.6 ± 4.56 | 15.9 ± 2.17 |
| NDF,% of DM[d] | 50.9 ± 4.57 | 51.5 ± 3.51 | 46.4 ± 4.78 |
| Indigestible NDF,% of NDF | 13.8 ± 6.81 | 9.4 ± 4.66 | 15.6 ± 3.11 |

[a] Net Energy Lactation (NEL)
[b] Protein Balance in the rumen (PBV)
[c] Amino acids absorbed from the intestine (AAT).
[d] Neutral detergent fiber (NDF)

### 2.5. *Animal performance – sampling and data collection*

#### 2.5.1. *Cow performance*

Throughout the 10 weeks of the study (weeks 0–9), and for a post-treatment period in weeks 10 and 11, machine milk yields were recorded automatically for each cow and milking. Due to lasting challenges with low machine milk yields at the same time as a perceived high udder fill (hereafter referred to as "inhibited milk ejection") in CC cows during milking, a veterinarian and the farmers were concerned about mastitis, and the farmers were also concerned about prolonged low milk yields. Hand massage of the udders before and during milking was attempted without success, and oxytocin was injected intramuscularly (i.m.) in doses of 2 mL (see Chapter 2.6 for more details) at milkings where it was considered a necessary treatment. Each oxytocin injection was recorded, and milk recordings affected by oxytocin injections were excluded from the analysis (see section Chapter 2.6 for details on how the data was handled).

Aliquot milk samples for the gross composition of machine milk were collected from individual cows in weeks 5 and 9, preserved with Bronopol (2-Bromo-2-nitropane-1,3 diol, Broad Spectrum Microtabs® II), and stored chilled (4 °C) until analysis of fat, protein, lactose, urea, free fatty acids (FFA) and somatic cell count (SCC) using Fourier Transform Spectrometry (Bentley FCM and IBC, Chaska, US). Because the i.m. oxytocin injections affect milk composition, we decided not to include the machine milk samples from week 9, since eight of ten CC cows got injected once that day. Instead, we used machine milk samples from 16 cows (8 from each treatment), taken post-treatment in September (weeks 14–18 postpartum, depending on the group).

Cows' BCS and BW were recorded on the first day on pasture and in week 9. BCS was estimated visually by the method developed by Geno for NRF (Geno, 2020), which is based on the method of Edmonson et al. (1989) by using a 5-point scale (1 = emaciated to 5 = severely over-conditioned). The cows were weighed using a portable scale (Gallagher, Hamilton, New Zealand) connected to an enclosure designed for handling and weighing livestock (IAE Agriculture, Stoke-on Trent, United Kingdom).

#### 2.5.2. Calf performance

Calves' intakes of concentrates were recorded on group level by weigh in-weigh out (with Brecknell ElectroSamson, England) at 07.30AM on four days each week. Milk amounts given to the ES calves were measured at each meal, and to record their milk intakes we also measured the milk residuals after each meal on four days each week.

Each calf was weighed after birth (IAE Digital Lamb Weigher, United Kingdom). Then, all calves in a group were weighed in their study weeks 6 and 9, and again during post-treatment in December 2021 (calf age between 6 and 7 months, depending on the group), using the equipment described above.

#### 2.5.3. Cow and calf health

Each cow was clinically examined and manually scored by a veterinarian on the first day on pasture and once in week 9, and each calf was examined on the calving day, the first day on pasture, once in week 6 and once in week 9, using a standardized health scoring system modified and supplemented with some extra investigations related to diseases that are more frequent on pasture (Table 3). Daily overall assessments, during which health deviations were recorded, were performed by the project staff. In case of fever, inappetence, lameness, mastitis, or udder injuries, the animal was subjected to veterinary examination, and diagnosis and treatment were noted.

In addition, quarter milk samples were taken for all cows in weeks 5 and 9 and from cows when they were diagnosed with mastitis, irrespective of week. The samples were taken according to the instructions of TINE SA's (Norway's largest producer, distributor, and exporter of dairy products) laboratory (TINE, 2019).

### 2.6. Statistical analysis

Statistical analyses were conducted in Minitab 21 Statistical Software. The response variables from the cow recordings were: "Milk per day" (daily machine milk yield/cow in kg), for the composition of machine milk in week 5 and post-treatment (week 14–18) components were in g/kg: "Fat", "Protein", "Lactose", in kg: "Energy corrected milk (ECM, calculated as kilograms of milk $\times$ (0.01 + 0.0122 $\times$ $g$ of fat/kg of milk + 0.0077 $\times$ $g$ of protein/kg of milk + 0.0053 $\times$ $g$ of lactose/kg of milk)", in mEq/L: "FFA", in mmol/l: "Urea" and in $10^3$/mL: "SCC", as well as "BCS decrease" and "BW decrease" (BCS score decrease/day or BW decrease in g/day, calculated by dividing the BCS decrease, and the BW decrease from the first day on pasture till week 9 by the number of days in this period for each cow). The calf response variable for statistical analysis was: "BWG" (daily BWG/calf in grams calculated from the weighings). Each response variable was analyzed separately using Mixed Effects Models.

Criteria for including and excluding data during the analysis were not established *a priori*. For the response variable "Milk per day" we excluded data from four days for four different CC cows (one day per cow; three days because only one milking was recorded, and one day because the recorded yield was considered erroneous). After this, we calculated milk per day by averaging the recorded milking for each day and each cow. Because of the use of i.m. oxytocin injections and its associated effects on machine milk yield (Bruckmaier, 2003), we then excluded the data from days with oxytocin injections and the following day, and if injected more than once, two consecutive days after the last injection. Thus, we removed on average 9 out of 77 days with milk recordings per CC cow due to oxytocin injections.

The full models were fitted for the different response variables, as shown below. For each of them, the residual plot from the model fit was visually checked for normality and homogeneity of variance. We transformed the contents in machine milk of "Urea" with $\text{Urea}^{-0.5}$ and "SCC" with $e^{(\text{SCC}+1)}$ so that they met the normality assumptions after the transformations. The other variables met the normality assumptions without any transformations.

**Table 3**
Clinical health parameters that were examined by a veterinarian for cows and calves in the two treatments: Cow-calf contact ($n$ = 10 cows and 10 calves), and early separation ($n$ = 9 cows and 10 calves). Mastitis, cell count, and udder or teat injuries were only examined in the cows.

| Clinical parameter | Score | | | | | Reference |
|---|---|---|---|---|---|---|
| Fecal consistency | 1 = Normal consistency | 2= Pasty, semi-formed | 3= Pasty with large amounts of water, content adhered in the perineum and tail | 4= Liquid with fecal content adhered in the perineum and tail | 5= Liquid with blood | (Hulsen, 2005) |
| Coughing | 1= No cough | 2= Single cough | 3= Induced repeated coughs or occasional spontaneous coughs | 4= Repeated spontaneous coughs | | Adapted from Renaud et al., 2018 |
| Temperature | < 38= Low | 38–39.5= Normal | > 39.5= Fever | | | Løken, 2013 |
| Temperature, calf > 2 weeks | < 38.5= Low | 38.5–40= Normal | > 40.0 Fever | | | Løken, 2013 |
| Respiration | Low | Normal | High | | | Løken, 2013 |
| Heart frequency | Low | Normal | High | | | Løken, 2013 |
| Lameness | 1= Normal | 2= Mildly lame | 3= Moderately lame | 4= Lame | 5= Severely lame | Sprecher et al., 1997 |
| Mastitis | Normal | Subclinical mastitis | Acute mastitis | | | Tine, 2017 |
| Cell count by Schalm test | 1 < 200 000 | 2 = 150 000 – 550 000 | 3 = 400 000 – 1.5 mill | 4 = 800 000 – 5 mill | 5 > 5 mill | Whyte et al., 2005 |
| Teat or udder injuries | 0= No wound/damage (completely intact skin) | 1= Wound/damage (any hair loss or damaged skin) | | | | Clin. Observation, vet. |

The full models for the response variables (Y) were:

1. Milk per day = intercept+ treatment+ group(treatment)+ cow (group; treatment)+ period+ parity+ treatment*period+ period*-parity+ DIM+ error
2. Fat, Protein, Lactose, ECM, FFA, Urea, or SCC (week 5) = intercept+ treatment+ group(treatment)+ cow(group; treatment)+ parity+ DIM+ error
3. Fat, Protein, Lactose, Total dry solids, ECM, FFA, Urea or SCC (week 14–18)= intercept+ treatment+ group(treatment)+ parity+ week+ error
4. BCS decrease= intercept+ treatment+ group(treatment)+ parity+ error
5. BW decrease= intercept+ treatment+ group(treatment)+ parity+ error
6. BWG= intercept+ treatment+ group(treatment)+ calf(group; treatment)+ sex+ period+ treatment*period+ sex*period+ birth weight+ error

In the models, "Treatment" was the main effect of treatment (fixed factor with two levels: CC, ES). "Group(treatment)" was the effect of each of the four groups (cows or calves in one group) within each of the two treatments (random factor). "Calf(treatment; group)" was the effect of each of the individual calves within each group within each treatment (random factor) and "Cow(treatment; group)" was the same but for the cows. The other fixed factors were "Parity" (two levels: primiparous and multiparous cows), "Sex" (two levels: bull and heifer calves), "Period" for "Milk per day" (four levels: weeks 0–6 (whole-day CCC), weeks 7–8 (weaning), week 9 (full separation) and weeks 10–11 (after separation)), "Period" for "BWG" (three levels: weeks 0–6, weeks 6–9 and week 9 till 6–7 months). The interactions were 2nd order interactions between the relevant fixed factors. We decided not to include interactions with parity and treatment or sex and treatment because we only had one primiparous cow among the ES cows and two bull calves among the CC calves. Subsequently, for the response variables "Milk per day" and "BWG" we ran post hoc analyses with Tukey pairwise comparison tests to examine the differences between each level of the factors and interactions having P-values less than 0.10. Significance was declared at $P < 0.05$ and a tendency was declared at $P < 0.10$. Regarding covariates, for model no. 1 and 2 the covariate "DIM" was removed, for model no. 3 the covariate "Week" was removed, and for model no. 6 the covariate "Birth weight" was removed ($P > 0.05$).

Other data shown descriptively are calves' intakes of concentrates, ES calves' intakes of milk, and cow and calf health. Individual intakes of concentrates (CC and ES calves) and milk (ES calves) were estimated by dividing the group's daily intake by the number of calves in the group. Although we do not know the variations in intakes of concentrates and milk among the individual calves, as these variables were recorded at group level, we decided to show the results as average intakes/calf/day for each week and treatment.

## 3. Results

### 3.1. Machine milk yield

The CC cows had lower machine milk yields than the ES cows both during the whole-day CCC period (fitted mean ± SE mean in kg/cow/day weeks 0–6: 10.74 ± 1.082 and 33.22 ± 1.280, respectively), during weaning (weeks 7–8: 9.08 ± 1.125 and 31.20 ± 1.317, respectively), separation (week 9: 16.26 ± 1.334 and 30.08 ± 1.395, respectively), and in the post-treatment period (weeks 10–11: 20.25 ± 1.171 and 27.92 ± 1.360, respectively) (Treatment*Period: $P < 0.001$). The CC cows' machine milk yields were lower during weaning in weeks 7–8 than during whole-day CCC in weeks 0–6 but increased in week 9 and increased more in weeks 10–11. The CC cows' machine milk yields were affected by inhibited milk ejection, see Table 7 for the number of cows with this issue, and number of oxytocin injections administered during the study. For the ES cows, machine milk yields were lower in weeks 0–6 than in weeks 7–8 and 9, similar in weeks 7–8 and 9, but lower than weeks 0–6, 7–8, and 9 in weeks 10–11. There was a significant effect of parity were primiparous cows had lower machine milk yields than multiparous cows (fitted mean ± SE mean in kg/cow/day: 18.59 ± 1.625 and 26.10 ± 0.833, respectively, $P = 0.001$). Fig. 3 shows machine milk yields for the CC and the ES cows in each week from week 0 till week 11.

### 3.2. Composition of machine milk

The CC cows had a significantly lower content of lactose in their machine milk compared to the ES cows in week 5 (difference: 3.3 g/kg of milk, Table 4a), and they also had a lower ECM (difference: 26 kg/day). For the other variables, there were no differences between the treatments. Post-treatment (weeks 14–18), there were no differences between the treatments for any of the variables ($P > 0.05$) (Table 4b). The numerically higher mean SCC in the ES cows compared to the CC cows' post-treatment was influenced by a high SCC in one ES cow.

### 3.3. Cow BCS, cow BW and, calf BWG

On pasture day one BCS (1–5-point scale) was on average (± SD) 3.90 ± 0.649 and 3.70 ± 0.655, and BW was on average (± SD) 657 ± 98.3 and 691 ± 47.1 kg/cow for the CC and the ES cows, respectively. Both the CC and the ES cows' mean BCS and BW decreased during the grazing period (Table 5). BCS decrease was not significantly different between the CC cows and the ES cows, while the BW decrease was significantly lower for the CC cows compared to the ES cows. There was a significant effect of parity for both BCS (fitted mean ± SE mean/cow/day for primiparous and multiparous cows: 0.010 ± 0.004 and 0.028 ± 0.003, respectively, $P = 0.003$) and BW decrease (in g/cow/day: 867 ± 210.3 and 1462 ± 120.5, respectively, $P = 0.028$).

Calves BW was on average (± SD) 40.4 ± 5.74 and 47.5 ± 5.17 kg at birth and 114.5 ± 9.14 and 119.6 ± 11.27 kg at 9 weeks for CC and ES calves, respectively. For the calves' daily BW gains, there was an interaction between treatment and period (Table 6, $P = 0.048$). Regardless of treatment, the calves had higher BWG in weeks 0–6 (whole-day CCC or high milk allowance) compared to weeks 6–9 (including weaning). The CC calves also showed higher daily BWG in the period from week 0 to 6 compared to the period from week 9 to 6–7 months (after weaning and separation). The ES calves had higher daily BWG in the period from week 9 to 6–7 months compared to the period from week 6 to 9. There was a significant effect of sex for BWG (fitted mean ± SE mean in g/calf/day for bull and heifer calves: 1183 ± 33.2 and 1078 ± 26.2, respectively, $P = 0.021$).

### 3.4. Calf intake of milk and concentrates

The ES calves' average milk intake was 10.7 L/calf/day from week 0 till week 6 (Fig. 4) (10.1 L/calf/day in weeks 0–3 and 11.6 L/calf/day in weeks 4–6), which was lower than the offered milk allowance of 12 L/calf/day in weeks 0–3 and 14 L/calf/day in weeks 4–6. ES calves started to eat concentrates earlier and they ate more concentrates than CC calves (Fig. 4). The CC calves calculated average concentrate intake was 142 g/calf/day from week 0 till 9 (19 g/calf/day weeks 0–6 and 428 g/calf/day weeks 7–9) and the ES calves average concentrate intake was 340 g/calf/day from week 0 till 9 (66 g/calf/day in week 0–6 and 980 g/calf/day in weeks 7–9).

### 3.5. Cow and calf health

Except for the challenges with inhibited milk ejection during milking in CC cows, and that more ES cows and calves were recorded with diarrhea scores > 3, the cow and calf health recordings (including

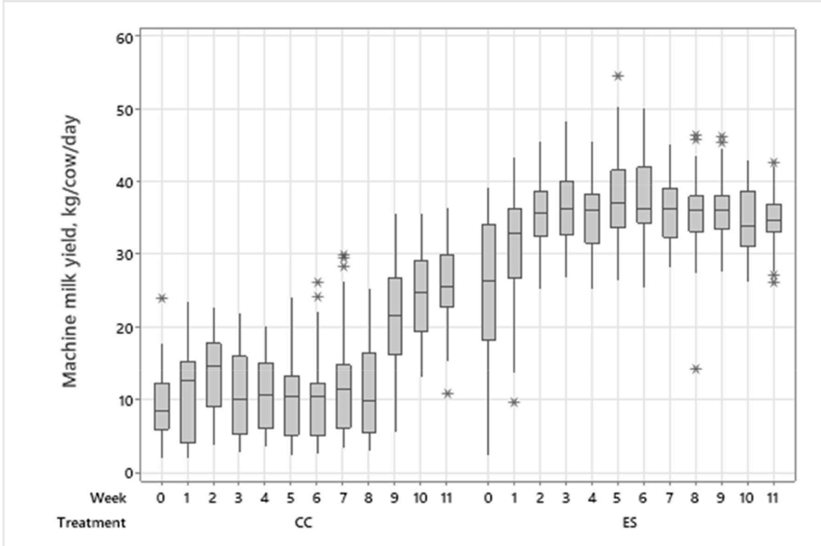


**Fig. 3.** Daily machine milk yield/cow in each of weeks 0–11 postpartum (boxplot with additional model estimates) for pastured cows from the two treatments: Cow-calf contact (CC=1) and early separation (ES=2).

**Table 4**
**a & b.** Composition of machine milk (fitted mean ± SE mean) in a. week 5 postpartum and b. post-treatment (weeks 14–18 postpartum) for pastured cows with cow-calf contact (CC) and pastured cows early separated from their calves (ES). Urea and SCC in week 5 are presented as back-transformed means with transformed fitted means ± SE means in brackets.

| a. Variable | Treatment | | Test statistics for treatment | |
|---|---|---|---|---|
| | CC ($n$ = 10) | ES ($n$ = 9) | DF Num, DF Den, F-value | $P$-value |
| Fat, g/kg | 25.3 ± 2.22 | 32.3 ± 2.59 | $F_{1.00,\ 2.43} = 4.48$ | 0.146 |
| Protein, g/kg | 31.3 ± 0.660 | 32.0 ± 0.756 | $F_{1.00,\ 2.70} = 0.26$ | 0.500 |
| Lactose, g/kg | 43.8 ± 0.659 | 47.1 ± 0.814 | $F_{1.00,\ 16.00} = 10.88$ | 0.005 |
| ECM, kg/day[1] | 7.74 ± 2.11 | 33.8 ± 2.32 | $F_{1.00,\ 2.18} = 72.32$ | 0.010 |
| FFA, mEq/L | 0.144 ± 0.0579 | 0.120 ± 0.0651 | $F_{1.00,\ 2.36} = 0.07$ | 0.810 |
| Urea, mmol/L | 2.19 (0.675 ± 0.0373) | 2.36 (0.650 ± 0.0402) | $F_{1.00,\ 2.07} = 0.21$ | 0.693 |
| SCC, $10^3$/mL | 24.4 (3.23 ± 0.458) | 47.8 (3.89 ± 0.565) | $F_{1.00,\ 16.00} = 0.89$ | 0.360 |
| b. Variable | CC ($n$ = 8) | ES ($n$ = 8) | | |
| Fat, g/kg | 38.7 ± 2.51 | 38.4 ± 2.59 | $F_{1.00,\ 1.98} = 0.01$ | 0.944 |
| Protein, g/kg | 34.4 ± 0.764 | 35.1 ± 0.888 | $F_{1.00,\ 13.00} = 0.40$ | 0.536 |
| Lactose, g/kg | 47.3 ± 0.756 | 46.8 ± 0.807 | $F_{1.00,\ 1.78} = 0.24$ | 0.675 |
| ECM, kg/day[1] | 23.2 ± 2.27 | 26.2 ± 4.54 | $F_{1.00,\ 1.98} = 0.89$ | 0.447 |
| FFA, mEq/L | 0.505 ± 0.107 | 0.703 ± 0.124 | $F_{1.00,\ 13.00} = 1.64$ | 0.222 |
| Urea, mmol/L | 5.19 ± 0.365 | 5.57 ± 0.375 | $F_{1.00,\ 1.98} = 0.55$ | 0.535 |
| SCC, $10^3$/mL | 39.6 ± 84.44 | 167.6 ± 98.03 | $F_{1.00,\ 13.00} = 1.10$ | 0.313 |

detailed clinical examinations and daily recordings) obtained throughout the study do not indicate noticeable differences regarding health between the two treatments.

Only the two oldest CC cows (lactation no. 5 and 6) were considered to have a normal milk ejection throughout the study. The challenge with inhibited milk ejection was most prominent during weaning and separation, and with three of the four primiparous CC cows. The cows had no events of respiratory diseases or lameness, but diarrhea (score > 3) was recorded in 67 % of the ES cows the first 2–3 days on pasture (Table 7). There were some challenges with mastitis, teat wounds, and udder injuries in both treatments (Table 7). Fever was recorded only in cows with clinical mastitis.

**Table 5**
Body condition score (BCS: 1 = emaciated to 5 = severely over-conditioned) decrease and body weight (BW) decrease in g/cow/day (fitted mean ± SE mean) from the first day on pasture and until week 9 postpartum, for cows from the two treatments: Cow-calf contact (CC, 56 days between the two measurements) and early separation (ES, 37 and 45 days between the two measurements for the two ES groups respectively).

| | Treatment | | Test statistics for treatment | |
|---|---|---|---|---|
| | CC ($n$ = 10) | ES ($n$ = 9) | DF Num, DF Den, F-value | $P$-value |
| Cow BCS decrease | 0.016 ± 0.003 | 0.023 ± 0.004 | $F_{1.00,\ 16.00} = 2.16$ | 0.161 |
| Cow BW decrease | 913 ± 143.5 | 1415 ± 177.2 | $F_{1.00,\ 16.00} = 5.32$ | 0.035 |

Diarrhea (score > 3) was recorded in 40 % of the CC calves and 100 % of the ES calves for one or a few days in the study (Table 7). Coughing was recorded in 30 % of the ES calves. None of the calves' general condition was affected by the diarrhea or coughing.

## 4. Discussion

Dairy cows have lower machine milk yields while having suckling calves (e.g. Mac et al., 2023; Wenker et al., 2022b), and the CC cows in this study delivered on average 23.7 kg less milk/cow/day than the ES cows during weeks 0–6 postpartum. Our results showed a sustained lower machine milk yield during weaning when the CC calves' suckling allowance was restricted to 1–2 h after milking (weeks 7–8 postpartum). Even though the CC cows' machine milk yield increased after suckling was completely prevented (weeks 9 and 10–11), it was still lower than for the ES cows. In another study where calves suckled for limited periods after milking, it was found that the machine milk yields in suckled versus non-suckled cows became similar within three weeks after weaning (Mendoza et al., 2010). Other studies found that suckled cows had similar machine milk yields as non-suckled cows within the first week after separation from their calves (de Passillé et al., 2008; Ospina Rios et al., 2023). However, these latter studies did not practice whole-day CCC, but rather part-time contact with restricted suckling allowance in periods (de Passillé et al., 2008) or half-day (Ospina Rios et al., 2023). Thus, it may seem that it is not necessarily the suckling itself that is an issue for milk ejection, but rather how the CCC system is

**Table 6**
Daily body weight gain (BWG) (mean ± SE) in three periods from birth to 6–7 months for cow-calf contact calves (CC, $n = 10$) and early separation calves (ES, $n = 10$). Means that do not share a letter are significantly different interactions between treatment and period ($P < 0.005$).

| Calf BWG, Treatment*Period | | | | | | Test statistics for treatment | |
|---|---|---|---|---|---|---|---|
| CC ($n = 10$) | | | ES ($n = 10$) | | | | |
| Birth–6 w | 6–9 w | 9 w–6–7 mo | Birth–6 w | 6–9 w | 9 w–6–7 mo | DF Num, DF Den, F-value | P-value |
| 1341 ± 49.7[A] | 1045 ± 49.7[CD] | 1058 ± 49.7[BCD] | 1254 ± 48.1[AB] | 920 ± 48.1[D] | 1164 ± 50.5[ABC] | $F_{2.00,\ 52.00} = 3.22$ | 0.048 |

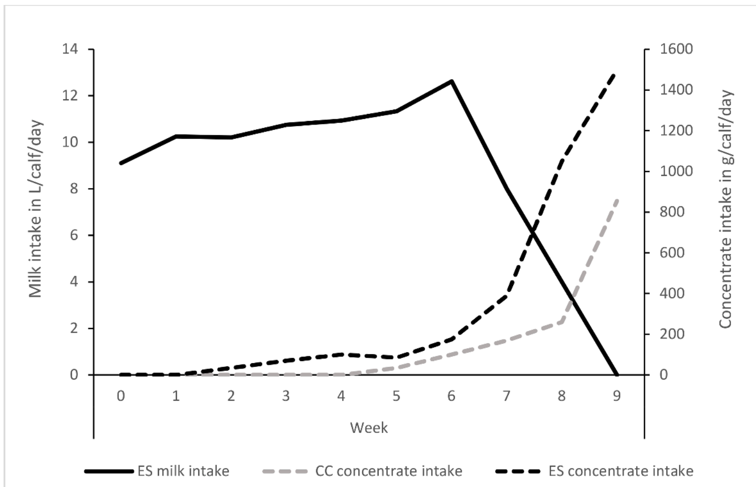


**Fig. 4.** Average individual calf milk intake (measured on group level, solid lines) in the early separation treatment (ES, $n = 10$) and average individual concentrate intake (measured on group level, dashed lines) in both treatments: Cow-calf contact (CC, $n = 10$) and ES. Both treatments were kept on pasture during the study.

**Table 7**
Number of pastured cows and calves with clinical diagnosis in the two treatments: Cow-calf contact (group CC1 and CC2) and early separation (group ES1 and ES2), and oxytocin injections in the number of treatments before weaning (weeks 0–6), as well as during weaning and separation (weeks 7–9).

| Health incident, cows | Item | CC1 ($n = 5$) | CC2 ($n = 5$) | ES1 ($n = 4$) | ES2 ($n = 5$) |
|---|---|---|---|---|---|
| Fecal consistency > 3 | No. cows | 0 | 1 | 4 | 2 |
| Coughing score > 1 | No. cows | 0 | 0 | 0 | 0 |
| Lameness | No. cows | 0 | 0 | 0 | 0 |
| Mastitis, clinical[a] | No. cows | 1 | 2 | 1 | 1 |
| Teat wounds/ udder injuries | No. cows | 1 | 2 | 0 | 2 |
| Inhibited milk ejection | No. cows | 3 | 5 | 0 | 0 |
| Oxytocin in. week 0–6 | No. of treatments | 12 | 2 | – | – |
| Oxytocin in. week 7–9 | No. of treatments | 26 | 26 | – | – |
| Health incident, calves | | CC1 ($n = 5$) | CC2 ($n = 5$) | ES1 ($n = 5$) | ES2 ($n = 5$) |
| Fecal consistency > 3 | No. calves | 1 | 3 | 5 | 5 |
| Coughing (scores 1–2) | No. calves | 0 | 0 | 0 | 4 |
| Lameness | No. calves | 0 | 0 | 0 | 0 |

[a] Detected bacteriae in mastitis diagnosis: Staphylococcus aureus, Staphylococcus epidermidis, Strepylococcus dysgalactiae; Staphylococcus warneri; Streptococcus agalactiae, Streptococcus uberis.

managed.

Practicing half-day CCC instead of whole-day might improve milk ejection, as Barth (2020) suggested that half-day CCC cows have better udder emptying in the milking parlor than whole-day CCC cows. This is supported by results showing higher machine milk yields in half-day compared to whole-day CCC cows (Barth, 2020: 12.6 vs 16.3 kg/cow/day, Neave et al., 2024: 12.1 vs 26.0 L/cow/day, respectively). Additionally, pasture studies indicate smaller differences in machine milk yields between half-day and non-CCC cows (Nicolao et al., 2022 difference: 11.4 kg/cow/day, Ospina Rios et al., 2023, difference: 9 L/cow/day) compared to the difference (23.7 kg/cow/day) found between whole-day and non-CCC cows in our study.

A limitation of our study is the lack of longer-term data on machine milk yields, so we do not know how the yields would have developed throughout the cows' full lactations. Except for being suckled or not, other factors may also affect cows' machine milk yields, like parity (Hansen et al., 2006). Regarding parity, it was a limitation in our study that the CC treatment had more primiparous cows than the ES treatment which only had one primiparous cow, as it is well-known that primiparous cows have lower milk yields than multiparous cows (Hansen et al., 2006). The imbalance in parity across treatments may have given larger differences in the amounts of machine milk yields than if parity was similarly balanced between treatments. Machine milk yields were also affected by inhibited milk ejection in CC cows, which was prominent in primiparous cows.

Although milk ejection of high-yielding *Bos taurus* cows is not conditioned on the presence of the calf as is the case for *Bos Indicus* (Ryle and Orskov, 1990), it is established that suckling (vs. milking) is associated with better milk ejection through higher oxytocin excretion (Lupoli et al., 2001). Thus, it is likely that oxytocin secretions in suckled cows in our study were too low to elicit a proper milk ejection in the milking parlor. Disturbed milk ejection during milking might specifically arise when cows leave their calves to be machine-milked (Kälber and Barth, 2014). However, since inhibited milk ejection was most prominent during weaning (weeks 7–8) in our study, when cows and calves had contact only in periods after milking, it could be that the cows were "holding back" their milk for their calves, similar as what de Passillé et al. (2008) experienced. When we reunited them after milking, we observed that cows and calves (most often a calf and its own dam) would immediately start suckling. As indicated in our study, inhibited milk ejection is more frequent in primiparous cows (Bruckmaier, 2005). Another factor is stress because of unfamiliar surroundings (Wellnitz and Bruckmaier, 2001), and in our study, the primiparous cows had no previous experience with the summer farm, the milking parlor, or the routines there. Training the primiparous cows to the milking routines prepartum could have enhanced their milk ejection (Ujita et al., 2021). Hand massage of the udder has been shown to stimulate milk ejection (Kentjonowaty et al., 2021), and this was tried without any success in our study. The cows' milk ejection could also have been enhanced if the calves had been suckling their dams for a few seconds before milking, as done with Bos Indicus crossbreeds by Mejia et al. (1998), and/or had been together with their calves during milking (Junqueira et al., 2005). It is well known that cows also experience stress during separation from their calves (Newberry and Swanson, 2008), even when it happens gradually (Johnsen et al., 2015). Such separation stress may have contributed to inhibited milk ejection being prominent during weaning and separation.

In our study, the only significant difference in the composition of machine milk between the CC and the ES cows was lactose content, where the CC cows had a lower content. These findings align with Wenker et al. (2022b), who found a tendency for lower lactose content in full CCC cows. They suggested that a few cases of high SCC in full CCC cows could explain this, referring to Costa et al. (2019). Despite the lower mean SCC in the CC cows in our study, the difference was not significant and is not likely the cause of the lower lactose content in the CC cows' machine milk in our study. The mean fat content in our study was 7.0 g/kg of milk lower in the CC cows than the ES cows, yet this difference was not significant, contrasting with other studies conducted indoors (Barth, 2020; Zipp et al., 2018) and on pasture (Nicolao et al., 2022; Ospina Rios et al., 2023) where the differences were -7.2, -6.6, -7.8 and -4.0 g/kg, respectively. The generally low fat contents observed in our study, which were below the Norwegian average of 4.4 % (Tine, 2023), may be attributed to grazing, as Adler et al. (2013) found lower fat content in machine milk from Norwegian farms during the pasture periods compared to the indoor periods. Our limited sample size and the greater variation in fat content, compared to for example lactose, might explain the lack of a significant difference. Power calculations prior to the study were used to determine group sizes, but non-random allocation to treatment may have deflated study power which secondarily may have affected our results.

Choosing the appropriate concentrate amounts for CCC cows presents a challenge, as it is difficult to determine the total milk production (machine milk+ suckled milk) in suckled cows. Despite the CC cows in our study receiving, on average, 2 kg less concentrates per cow per day compared to the ES cows, the decrease in BW was significantly lower for the CC cows than for the ES cows. A lower decrease in BW and BCS in full CCC cows differs from findings in part-time CCC (Bar-Peled et al., 1995). In our study, this result might have been affected by the potentially higher milk yields and thus higher energy requirements in the ES cows compared to the CC cows. It is known that BCS decreases with higher parity (Harrison et al., 1990; Pryce et al., 2001), and the higher number of primiparous cows among the CC cows in our study complicates direct comparisons between the two treatments. However, we clearly observed that the ES cows became thinner than the CC cows, though the difference in BCS was not significant. The difference in BW was significant, but BW as single-point measures might be affected by factors as rumen fill, and the results would have been more reliable with more frequent weighings, ideally twice each day of weighing. Studies examining cows' BCS and BW decrease in CCC systems are limited. Recent studies by Nicolao et al. (2022) and Ospina Rios et al. (2023) included this but found no difference between part-time CCC and non-CCC cows. Management of CCC systems on pasture and level of contact between cow and calf might affect cows' machine milk yields, as well as BCS and BW, which may explain different results across studies.

The similar calf BWG between the two treatments in our study can be compared to studies with suckling calves versus studies with calves given ad libitum of milk artificially where similar BWG also have been found. Suckling: between 1.2 and 1.4 kg/calf/day (Grøndahl et al., 2007; Mac et al., 2023), artificial milk-fed ad libitum: between 1.1 and 1.3 kg/calf/day (Miller-Cushon et al., 2013; Wormsbecher et al., 2017). In our study, while the CC and the ES calves exhibited similar BWG, there may have been variations in milk intake. Suckling calves with whole-day CCC engage in 4–10 suckling bouts daily (de Passillé, 2001), with about half occurring at night (Ewbank, 1969). However, the ES calves in our study lacked nighttime access to milk. Additionally, the ES calves had a higher energy intake through concentrates and perhaps also grazing, potentially compensating for a reduced milk intake. Both the CC and ES calves in our study showed a decrease in BWG during the period that included weaning (weeks 6–9) compared to the pre-weaning period (weeks 0–6). The mean BWG in weeks 6–9 was higher in the CC calves compared to the ES calves, but the difference was not significant. It is likely that the CC calves had higher milk intakes during weeks 7–8 due to issues with inhibited milk ejection in their dams. The ES calves seemed to compensate for their lower milk allowance by eating more solid feed. This, along with the small sample size, might explain why the difference in BWG between treatments was not significant. Additionally, weighing the calves more frequently during this period could have been beneficial.

Our descriptive data on calf concentrate intakes showed that the ES calves consumed concentrates earlier and in larger amounts than the CC calves. Similar findings have been detected for calves kept both indoors (Fröberg et al., 2011) and on pasture (Ospina Rios et al., 2023). However, factors affecting concentrate intakes in our study may be affected by the calves grazing where the ES calves were grazing more than the CC calves during behavioral observations in week 6 (Johanssen et al., 2024), and the ES calves had a somewhat different botanical composition and a slightly lower pasture quality than the CC calves (Table 2). Additionally, the ES calves were also milk-fed in the calf hide and used the calf hide where the concentrates were located more than the CC calves (Johanssen et al., 2024). The CC calves had free access to milk through suckling (except during cows' milking) in weeks 0–6, whereas the ES calves were fed four meals daily. The ES calves in our study had an average milk intake of 10.7 L/calf/day in weeks 0–6 when their milk allowance was close to ad libitum. Some studies with calves fed ad libitum of milk artificially also found calves' milk intakes to be around 10 L/calf/day (Jasper and Weary, 2002; Welboren et al., 2019), while in other studies milk intakes were up to 13–14 L/calf/day (Miller-Cushon et al., 2013; Wormsbecher et al., 2017). It is possible that our ES calves would have drunk more milk if the meals had been more evenly distributed around the clock or with ad libitum access through an automatic milk feeder. Comparing the CC cows' machine milk yield during the whole-day CCC period with the period in weeks 10–11, the difference was 12.2 kg/cow/day. This may more realistically correspond to the CC calves' actual milk intake than the difference of 23.7 kg/cow/day in the CC versus the ES cows' machine milk yields in weeks 0–6 since the calves' daily BWG were similar.

There were some health challenges with the cows during our study, but the calves were generally healthy. There were no obvious differences in cow or calf health between the two treatments, except for some more diarrhea in ES, and the challenges with inhibited milk ejection in CC cows explained above. The increased incidence of diarrhea in ES cows was most likely due to delayed access to silage on pasture as ES cows had ad libitum access to silage from day four while CC cows had this from day one (explained in Chapter 2.4). For ES calves, diarrhea occurred during the weaning period when they got less milk and increased their concentrate intake rapidly. Interviewed farmers practicing CCC both indoors and on pasture have mentioned higher calf BWG and better health among the main benefits of applying these systems (Johanssen, 2024; Neave et al., 2022; Vaarst et al., 2020), unlike our findings. Typically, artificially reared calves are kept indoors, and may be individually housed for up to 8 weeks. In contrast, our artificially reared calves were kept in groups on pasture.

Further research should aim to study management to improve milk ejection in pastured dairy cows with CCC. This is crucial for ensuring the welfare of the cows, facilitating the farmers' work, and reducing the risk of lower profitability when practicing CCC systems in dairy farming. Potential strategies include allowing calves to accompany cows to the milking parlors, if feasible, using mobile milking robots for milking CCC cows on pasture, and training primiparous cows in milking routines before calving. One should also examine how to enhance milk ejection in the stressful period around cow-calf separation, including more research on gradual separation methods on pasture to reduce stress.

## 5. Conclusion

Inhibited milk ejection during machine milking was a challenge in CC cows, prompting oxytocin injections to prevent mastitis. Allowing calves full CCC or providing whole milk near ad libitum can result in similar BWG and health in calves. Further research should explore strategies to enhance milk ejection in pastured CCC cows.

## Ethics approval and consent to participate

No ethics approval was required for this study.

## CRediT authorship contribution statement

**Juni Rosann E. Johanssen:** Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Steffen Adler:** Writing – review & editing, Supervision, Project administration, Methodology, Formal analysis, Data curation, Conceptualization. **Julie Føske Johnsen:** Writing – review & editing, Supervision, Project administration, Methodology, Formal analysis. **Kristin Sørheim:** Writing – review & editing, Supervision, Project administration, Funding acquisition, Data curation, Conceptualization. **Knut Egil Bøe:** Writing – review & editing, Supervision.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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