Animal 18 (2024) 101318

Contents lists available at ScienceDirect

Animal

The international journal of animal biosciences

Effects of whole-day versus half-day cow-calf contact on cows' and calves' performance

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ARTICLE INFO

Article history:
Received 16 July 2024
Revised 13 August 2024
Accepted 26 August 2024
Available online 2 September 2024

Keywords:
Animal welfare
Dairy cattle
Dam rearing
Milk yield
Nursing

ABSTRACT

Cow-calf contact systems (**CCCs**), where dairy cows nurse their own calves for several weeks while being milked, have some advantages in terms of animal welfare. However, one major challenge is the loss of collected milk due to suckling and milk ejection problems during milking. Reducing daily CCC can decrease milk losses. Our study investigated the effect of half-day CCC during daytime (**HC**, n = 11 cows) compared to whole-day contact (**WC**, n = 13) and no contact (**NC**, n = 14) on harvested milk yield, milk content, udder health, calving interval, and calf weight gain in a dual purpose breed-herd with concentrate-free feeding. 'Nursing' (9 weeks *postpartum*) was followed by separation of cow and calf, but still with visual CCC and twice daily milk feeding by nipple buckets (6 l per day, 'in sight/milk feeding'). During the 11th–12th week, calves were housed out of sight and gradually weaned. Calves of NC were separated from their mothers 1 day *postpartum*, obtained 6 l whole-milk per day and were gradually weaned. During 'nursing', NC and HC cows gave more milk than WC in the morning. In the evening, HC and WC gave less milk than NC, but HC cows had also a slightly lower milk yield than WC. During 'nursing', a reduced fat content (−1% point) pointed at milk ejection problems in both CCC treatments independent from daytime. After separation from the calf (periods: 'in sight/milk feeding' and 'out of sight/weaning') and over the whole lactation, milk yield between HC and the other treatments did not significantly differ while WC cows gave less milk than NC cows. Protein contents were higher in dams than in NC. There were no indications of differences in the incidence of mastitis, somatic cell score or calving interval between treatments. During 'nursing', NC calves gained about 0.3 kg less per day than CCC-calves (n_{NC} = 12, n_{HC} = 7, n_{WC} = 10). After separation from the mother, there was a growth check in both CCC groups. During 'in sight/milk feeding', HC gained less weight than NC and WC (n_{NC} = 11, n_{HC} = 9, n_{WC} = 10). Hereafter, weight development did not differ. Two weeks after weaning, nursed calves were still significantly heavier than NC (n = 5–8). Nine weeks of HC during the day compared to WC helped to reduce losses of sellable milk during the nursing period and over the whole lactation while calf development was similar.

Implications

Early *postpartum* separation of dairy cow and calf is under increasing welfare scrutiny. If cow and calf have whole-day contact milk losses are high, which can be an obstacle for farmers to implement this system. Sellable milk yield can be increased by reducing the daily duration of cow-calf contact which, however, also reduces the possibility for mother-calf interactions as part of their natural behaviour. As a possible compromise, we investigated the effects of half-day contact between morning and evening milking on productivity and found that milk loss was reduced in comparison to whole-day contact while cow health and calf growth were not affected.

Introduction

When European dairy cows (*Bos taurus*) are allowed to nurse their calves and are additionally milked (cow-calf contact = **CCC** with the dam), the amount of sellable milk is reduced. Previous research has reported reductions from 7 to 16 kg per day (Mendoza et al., 2010; Barth, 2020) or 26.5–58.2% compared to non-suckling systems (e.g. Passillé et al., 2008; Wenker et al., 2022). This reduction results in part from the calves suckling from their dam (i.e. cows rearing their own calf) up to 14 kg of milk per day (e.g. Passillé et al., 2008). Bucket−fed calves often receive less

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https://doi.org/10.1016/j.animal.2024.101318
1751-7311/

milk, waste milk or milk replacer, for example 10–12% of live weight (Ivemeyer et al., 2022). Under such conditions, more harvested milk can be sold. Another reason for the reduction is disturbed milk ejection during milking in dams caused by lower oxytocin release (Akers and Lefcourt, 1984; Passillé et al., 2008). This is reflected by slower milk flow rates (Mendoza et al., 2010; Zipp et al., 2018), a higher amount of residual milk after milking (Passillé et al., 2008) and a reduced fat content in collected milk by 0.5–1.5% points (e.g. reviewed by Johnsen et al., 2016; Nicolao et al., 2022; Wenker et al., 2022).

Besides vocalisations and other behaviours indicative of stress during separation and weaning and the need to provide adequate housing for both cow and calf in one system (Eriksson et al., 2022), the loss of harvested milk is a major challenge to the feasibility of CCC systems (reviewed by Johnsen et al., 2016; Neave et al., 2022). Otherwise, CCC carries a number of advantages for the calves' and dams' welfare: they can perform mother-calf behaviour and some studies point to long-lasting positive effects on the behaviour of dam-reared calves (Buchli et al., 2017) and heifers (Wagner et al., 2012; Zipp and Knierim, 2020). Calves have high weight gains during the nursing period and cross sucking is reduced to a minimum (reviewed by Johnsen et al., 2016; Meagher et al., 2019; Bieber et al., 2022). Furthermore, the vagal activity of dams with whole-day contact was shown to be higher, pointing at a more relaxed state (Zipp et al., 2018). Results regarding effects of prolonged CCC on animal health are heterogenous (reviewed by Beaver et al., 2019; Bieber et al., 2022; Wenker et al., 2022).

Consumers criticise the early separation of dairy cows and calves in several countries (reviewed by Placzek et al., 2021). The number of farms with CCC has increased in several European countries since 2010 (Eriksson et al., 2022). To support farmers, who want to implement CCC, it needs to be further evaluated how to tackle alveolar milk ejection problems during milking. To date no effective, feasible and sustainable way to heighten oxytocin release during milking in nursing cows has been found (reviewed by Johnsen et al., 2016). Another approach to increase milkability may be to decrease the time of CCC. Short-time CCC twice per day for 15–60 min after milking has been shown to decrease milk losses to 6.9–9.4 kg per day (Passillé et al., 2008; Mendoza et al., 2010; Nicolao et al., 2022) compared to whole-day contact systems with milk losses of 12.2–16.1 kg per day (Barth, 2020; Wenker et al., 2022). However, in short-time CCC systems calves can only suckle twice daily, which is not in line with their natural behaviour (e.g. Lidfors et al., 1994). Furthermore, depending on contact duration and place, affiliative behaviour and social learning from the mother or other cows are considerably limited. Half-day CCC may be a feasible compromise, where the animals' and farmers' needs are considered. If half-day CCC was allowed during the night (1800–0500 h), the harvested milk yield during the nursing phase and during the rest of the lactation was higher compared to whole-day and short-time CCC (Barth, 2020). However, probably the opportunity for mother-calf interactions is reduced during night contact, considering the natural rhythm of activity and resting. Therefore, half-day CCC during the day may be an approach where calves and cows can perform more natural behaviour and at the same time, milkability may be less impaired than in whole-day CCC. Neave et al. (2024a) recently showed that Holstein cows with half-day CCC during the day gave more milk during morning milking and had similar milk yields during afternoon milking compared to cows with whole-day CCC. However, other parameters of animal productivity and long-lasting effects were not assessed. Other studies on half-day CCC have focused on animal behaviour (Veissier et al., 2013; Roadknight et al., 2022; Bertelsen and Jensen, 2023a; Neave et al., 2024b; Jensen et al., 2024) or did not compare the half-day system with whole-day CCC (Johnsen et al., 2015a; Johnsen et al., 2015b; Nicolao et al., 2022; Ospina Rios et al., 2023). Therefore, the aim of the current study was to investigate the effect of half-day CCC in comparison to (1) whole-day CCC and (2) a control treatment without CCC on machine−collected milk yield during and after the nursing phase, on milk fat and protein content, udder health, fertility and calf weight gain. As CCC systems are often used in organic farming (Eriksson et al., 2022), we investigated these questions in a low−input system, with a dual−purpose breed and concentrate-free feeding.

Animals, material and methods

The experiment was conducted from October 2011 to June 2012 at the organic research farm of the University of Kassel, Germany. At the time of the experiment, the farm kept about 95 dairy cows plus replacement stock of the dual-purpose breed German Black Pied Cattle. They were predominantly horned. Mean milk yield the year before the experiment was 5 434 kg per year with 4.21% fat and 3.33% protein. A total mixed ration consisting of grass-clover silage, alfalfa silage, grass silage, maize silage, washed raw potatoes and straw were fed without adjustment to individual milk yields. Cows received no concentrate.

The 38 experimental cows (lactation numbers 1–9) were evenly allocated to three treatments: no CCC (**NC**), half-day CCC (**HC**) and whole-day CCC (**WC**). Randomisation considered parity (primiparous vs multiparous) and in multiparous cows: expected calving date, milk yield and milk flow of the last one or two lactations: In each treatment, it was planned to have three first lactating cows. However, as the last first lactating cow in the experiment, had a stillborn calf, she was allocated to NC instead of HC. Further one HC cow and her calf were excluded from analysis because the cow had a serious udder oedema and milking was impaired (n_{NC} = 4 primiparous + 10 multiparous, mean lactation number 3.6 ± 2.6, n_{HC} = 2 primiparous + 9 muliparous, mean lactation number 3.1 ± 1.9, n_{WC} = 3 primiparous + 10 multiparous, mean lactation number 2.7 ± 1.4). Multiparous cows with a previous record of very high or low milk flow (LactoCorder® data) and high or low milk yield were equally distributed over the treatments (mean ± SD of the last lactation 305 days-yield: NC = 5 590.44 ± 1 165.07 kg, HC = 5 921.22 ± 503.05 kg, WC = 5 837.40 ± 901.01 kg).

The cows of the three experimental treatments were housed in the same deep litter barn on a deep litter lying area and concrete feeding area plus concrete outdoor run with automatic scraper, but they were separated by a fence. Management and feeding of all treatments were the same. Space allowances were 6.3–7.1 m^2 lying area plus walking area per cow indoors and 3.9–4.5 m^2 per cow outdoors. For calving, all cows were kept individually in a deep litter calving pen (3.50 × 5.25 m). During the time, the calves stayed in the calving pen, suckling was assisted three times a day until the calf was observed suckling regularly on its own. After calving, cows were milked for the first time at the next regular milking.

The 2x6-herringbone parlour (System Happel GmbH, Friesenried, Germany) operated with 40 kPa vacuum, common mode, pulsation rate 60 double pulses per minute, pulsation ratio 60:40. Automatic milk-out started at 1 000 g per minute milk flow and automatic cluster take-off was at 250 g per minute. In one NC and two HC cows, milk-out and cluster removal were carried out manually, as otherwise, they would not have been milked out properly. This special treatment of these animals was already routine on the farm before the study started. Udder preparation consisted of foremilking and cleaning of the teats with one to three wet udder wipes per cow. About one minute after the start of udder preparation, milking clusters were attached. If one of the quarters was empty during milking while the others were still giving milk, the milking cluster of this teat was detached and a dummy plug was inserted. After the removal of all milking clusters, emptiness of quarters was checked manually. If necessary, milking clusters were attached again. After milking, NC cows in general and HC cows in the afternoon were dipped with an iodine-containing agent (Kenostart, Cid Lines, Ieper, Belgium, 3 mg iodine per g). Cows of the WC treatment were not dipped during the nursing period. All lactating cows were driven to the waiting area with no access to the calves at about 0600 and 1730 h daily. After milking, cows went back into the barn or the calving pen and could re-unite with their calves, if applicable.

Treatments

The experiment lasted 9 months. One to four cows (on average 2.1 cows) calved per month and treatment during the first 6 months of the experiment. Initially, in each treatment, 10 dry cows, expected to calve within the next months, were grouped. Cows with the latest calving dates (1–4 cows per treatment), entered the treatment group only after calving, in order to provide them with an adequate feeding ration during their dry period. However, the multiparous cows had been kept together with the other cows in one herd prior to the experiment. Before the experiment started, the first lactating cows were kept in a separate group of heifers. At the start of the experiment, depending on calving date, they were either grouped with the multiparous cows in one of the three treatment compartments or with the other multiparous cows with the latest calving dates of the experiment (mixed over all treatments) in a deep litter barn. Immediately before individual calving, cows were separated in a calving pen and returned to or entered their respective treatment pen with (HC, WC) or without (NC) their calf. Calves at the age of 9 weeks left the treatment pen. Male calves of all treatments were sold after the 10th week of life.

No contact

The four primiparous and 10 multiparous cows of this treatment were separated from their calf half a day after birth or had stillborn calves. The NC calves consisted of five female and five male calves (including two twin male calves). To offset the data-loss due to dead calves, additional weight gains of all calves born during the study period by non-experimental cows were recorded (one male, three females). In total, data of six male and eight female calves were analysed. While NC cows stayed in the calving pen for 1 day, except for the milking time, half a day after birth, the calves were moved into individual calf igloos (1.7 m^2 straw bedded lying area, 1.5 m^2 outdoor area). During the 1st week after birth, calves were fed three meals of 1.5 l colostrum per day. They had access to water *ad libitum*. In the 2nd week, they were housed in an open-sided barn in groups of up to seven calves of approximately the same age in straw-bedded pens (3.1×6.0 m^2) with a bowl drinker. Thenceforward calves obtained 2×3 l whole milk per day, which was the established feeding regime on the farm. Milk and colostrum were heated to 39 °C and fed by a nipple bucket. Calves had *ad libitum* access to the cows' total mixed ration, concentrate and sometimes hay.

Whole-day contact

The three primiparous and 10 multiparous cows had full WC calf-contact during the first 9 weeks of lactation. During the first 3 days *postpartum*, they stayed in the calving pen with their calf, except for milking twice daily. On the fourth day *postpartum*, mother and calf were moved into the pen of the WC treatment in the cows' barn. Eight female and five male calves were in the WC treatment. WC calves could freely suckle their dam day and night and move between the cows' area and a calf creep. The calf creep consisted of a group igloo (14.9 m^2) with straw bedding and trough with cows' total mixed ration, concentrate and sometimes hay. In an outdoor area (29.0 m^2), water was provided in a 10 l bucket. Cows of the WC treatment were separated from their calves during each milking for about 15–45 min.

Half-day contact

The two primiparous and nine multiparous HC cows had six female and five male calves. 'Half day' cows and calves had 3 days of whole-day contact in the calving pen after birth. After cow and calf were moved to their treatment pen, the calves were locked into the calf creep over the night. Cow-calf contact started after morning milking and ended with the start of afternoon milking (0630–1730 h). Besides these experimental conditions, everything was comparable for HC and WC contact cows and calves.

Experimental phases

The experimental phases described in Table 1 were applied to both CCC treatments. The same time spans were compared between NC and CCC cows and, accordingly, the experimental phases were also named 'nursing','in sight/milk feeding' and 'out of sight/weaning' for the NC cows, although they did not experience these conditions and changes during these phases. Calves of all treatments were weaned from milk in the same way. The phases 'in sight/milk feeding' and 'out of sight/weaning' started always on a Wednesday. There was one straw-bedded separation pen (5.0×5.0 m) per treatment located about 2 meters apart from the outdoor run of the cows. One to three HC or WC calves were moved to the separation pen at a time and grouped together with one NC calf of approximately the same age. Therefore, calves were never isolated. After this phase, male calves were sold and female calves of the CCC treatments were grouped with the NC calves in the calf barn.

Data collection

Recording of milk yield and composition started at the earliest 5 days after calving. Milk yield was assessed with the calibrated automatic milk yield recording of the milking machine (Memolac 2, MM8, System Happel, NEDAP Agri BV, Groenlo, The Netherlands) on 4 days per week (Thursday to Sunday). Milk yields lower than 1 kg, which could not be recorded by the milking machine occurred during afternoon milkings in nursing cows and in one primiparous NC cow. In these cases, 0.5 kg was taken as yield for this milking. If the milk yield of one milking was missing due to technical reasons (2.8%), the mean milk yield of the animal of that week, adjusted to morning or evening milking, was used instead. For the analysis of milk fat and protein content and somatic cell count (**SCC**), composite milk samples were taken at four milkings per week (Monday afternoon to Wednesday morning) with Meltec milk meters (NEDAP Agri BV, Groenlo, The Netherlands). During 'out of sight/weaning', milk samples were analysed only during the 1st week. Fat and protein contents were analysed with IR spectroscopy and somatic cell count with flow cytometry according to milk recording standards. Somatic cell count was transformed to somatic cell score (**SCS** = log2(SCC/(100 000)) + 3) (Wiggans and Shook, 1987). If milk showed clinical signs of mastitis, milk samples could not be analysed. Applying a maximum threshold of 100 000 cells per ml to be expected in healthy udders (DVG, 2012), we analysed an additional variable: the proportion of milkings with SCC > 100 000 cells per ml and included the milkings with clinical mastitis. Furthermore, the incidences of new udder infections during the 1st 12 weeks *postpartum* were recorded. Clinical mastitis was defined as visible or palpable abnormalities of the udder (being red, hard, swollen or hot) or visible abnormalities of the milk

Table 1
Experimental phases, housing and management of half-day (HC) and whole-day cow-calf contact (WC) in German Black Pied dairy cattle.

Phase	Weeks of lactation	Cow-calf-contact	Housing of calves	Milk source and amount of milk
Nursing[1]	1st–9th	HC or WC full contact	Cow barn + calf creep	Dam with HC or WC access
In sight+ Milk feeding	10th	Visual and acoustic contact	Separation pen	Nipple bucket, 2×3 l per day
Out of sight+ weaning[2]	11th–12th	Acoustic contact	Calf barn	Nipple bucket, 11th week: 2×2 l per day 12th week: 2×1 l per day
Post weaning[3]	13th–14th	Acoustic contact	Calf barn	–

[1] first 3 days *postpartum* in the calving pen with WC contact also for HC.
[2] analysis of milk composition until the 11th week, milk yield recording until the 12th week.
[3] only assessment of calf BW and weight gain

(flakes, clots or watery appearance). One HC and one WC cow had blood in the milk during two milkings. No data were collected in these cases.

For cows with lactation information for at least 220 days during the experimental lactation, also the mean daily milk yield of lactation was calculated. If the lactation was longer than 305 days, only the milk yield up to this day was integrated in the average daily lactation yield. For all experimental cows that calved again, calving intervals were calculated based on milk reports. As the non-experimental cows in the same herd had routinely received the same treatment as the NC cows, they were included in this category for this analysis. Cows with assisted calvings were excluded from analysis (two NC cows). As one cow in each treatment had twins, this factor was not further considered in the analysis of calving interval. Calves were weighed on the day of birth, after ‘nursing’ (9 weeks after birth), after ‘in sight/milk feeding’ (10 weeks after birth), ‘out of sight/weaning’ (12 weeks after birth) and 2 weeks after weaning with an electronic scale with a precision of ± 1 kg (EziWeigh2, Tru-Test Group Limited, Auckland, New Zealand). Daily weight gains were calculated per animal for the experimental phases. Missing values due to missing or incorrect weighing occurred so that the number of animals per treatment and phase partly differ.

Statistical analysis

All analyses have been done in R (version 4.0.3, R Core Team, 2020). As all treatments had essentially the same housing and management conditions, separated only by a fence, and each cow-calf pair was followed at different times and in a changing group composition with new calves joining and others leaving the group (except for NC where only cows left and joined around calving), our statistical unit was the individual cow or calf.

Data of cows during the experimental phases

It was visually checked, whether there were treatment-phase interactions and whether daytime had an influence on the dependent variable. Normal distribution of the model residuals was checked using QQ-plots, kurtosis and skew. Homogeneity of model residuals was ascertained with scatterplots (y-axis: fitted values of the model, x-axis: model residuals). Data of machine milk yield needed to be transformed (square root). For SCS and the percentage of milkings with an SCC > 100 000 cells per ml, no interaction and no influence of daytime could be detected and therefore one average value per animal and phase was entered in a linear mixed effects model (Bates et al., 2015) with treatment and parity (primiparous vs multiparous) as fixed factors and animal as random factor (repeated measurements).

For the other dependent variables, a mean was calculated for each phase for morning and afternoon milking. The dependent variable protein content during ‘nursing’ and the variables machine milk yield, fat content and protein content during ‘in sight/milk feeding’ and ‘out of sight/weaning’ met all model requirements for a linear mixed effects model per phase. Fixed factors were treatment (NC, HC, WC) and daytime (morning, afternoon), and animal was included as random factor. To avoid a possible bias due to the unbalanced distribution of parity over treatments on results regarding machine milk yield, SCS and percentage of milkings with a SCC > 100 000 cells per ml, parity was included as an additional a priori fixed factor in these models (results not presented). The models regarding machine milk yield and fat content during ‘nursing’ did not fulfil the statistical requirements for mixed models. These variables were therefore analysed with one mean per daytime via ANOVA. In general, Tukey’s *posthoc* test was used when treatment had a *P*-value below 0.05. Potential differences between treatments concerning incidences of clinical mastitis were analysed using Fisher’s exact test (Warnes, 2013). Only data of multiparous cows were considered, as only multiparous cows had mastitis and the number of primiparous animals differed between treatments.

Cow data of the lactation and data of calves

ANOVA was used to analyse the effect of treatment on calving interval, average daily milk yield during the lactation (including lactation number as an additional independent variable) and daily weight gain of calves during ‘nursing’ and’in sight/milk feeding’ (including sex as an additional independent variable). If treatment had a *P*-value below 0.05, Tukey’s *posthoc* test was used. Homogeneity of residuals was ascertained with Levene-test (Fox and Weisberg, 2019). Normality of residuals was confirmed using qq-plots, kurtosis and skew. Possible treatment effects on daily weight gain of female calves during ‘out of sight/weaning’ and ‘post weaning’ and on their live weights 2 weeks after weaning were analysed by Kruskal-Wallis tests due to small animal numbers. If the treatment-effect was $P < 0.05$, the Wilcoxon-rank-sum test was used as a *posthoc* test.

Presentation of data

For linear mixed models and ANOVA, means and SD are presented. Data that were analysed with non-parametric tests are presented as boxplots. In treatment effects with $P > 0.05$, the effect size was calculated with Eta^2 = sum of squares of the treatment effect/ total sum of squares of the model. According to Cohen (1992), the results were interpreted as small (≥ 0.01), medium (≥ 0.06) and large effect size (≥ 0.14). For results from Tukey’s *posthoc* tests, effect sizes were calculated with $r = \sqrt{(t^2/(t^2 + df))}$ and for Wilcoxon-rank-sum tests with $r = z/\sqrt{n}$ (Rosenthal, 1991, p. 19). Effect sizes were regarded small, medium or large when $r \geq 0.10$, $r \geq 0.30$ or $r \geq 0.50$, respectively (Cohen, 1992). Where data are presented as figures, model estimates, lower and upper CI for treatment (back-transformed in case of machine milk yield) and RSD are given in the supplementary material (‘nursing’: Supplementary Table S1, ‘in sight/milk feeding’ and ‘out of sight/weaning’: Supplementary Table S2).

Results

Milk yield

Daily milk yield until 12th week of lactation

Milk yields below 1 kg (set at 0.5 kg) occurred only during afternoon milkings: In HC-dams in 43.9% during 'nursing', 0% during'in sight/milk feeding', 5.4% during 'out of sight/weaning'. In WC dams, they occurred in 17.9% of milkings during 'nursing', in 11.8% during'in sight/milk feeding' and in 2.0% during 'out of sight/weaning'. In the NC treatment, it occurred in only 1.1% of milkings during 'nursing'. While milk yield was relatively stable over all phases in NC cows, it was on average 9.9 kg per day lower during 'nursing' in HC cows (45% of NC yield) and 13.5 kg per day (62%) lower in WC cows, but increased in both CCC treatments after nursing ended (Fig. 1A).

During 'nursing', WC cows gave less milk in the morning than HC (t = −5.93, P < 0.0001, r = 0.71) and NC (t = −7.97, P < 0.0001, r = 0.81). There was no statistical difference between NC and HC (t = 1.58, P = 0.265, r = 0.26). In the afternoon, both treatments with CCC gave less milk than NC (HC vs NC: t = −11.84, P < 0.0001, r = 0.89; WC vs NC: t = −9.11, P < 0.0001, r = 0.84). Cows of the HC treatment yielded slightly less milk than WC (t = −3.08, P = 0.011, r = 0.46; Fig. 2A). During 'in sight/milk feeding' and 'out of sight/weaning' machine milk yield of HC did not differ from NC (t = −0.87, P = 0.6613, r = 0.14; t = −1.55, P = 0.2680, r = 0.18, respectively). However, WC gave in tendency less milk than HC (t = −2.20, P = 0.0719, r = 0.34) and significantly less milk than NC cows during 'in sight/milk feeding' (t = −3.24., P = 0.0033, r = 0.47). The latter difference remained during 'out of sight/weaning' (t = −2.84., P = 0.0126, r = 0.42, Fig. 1A).

Mean daily milk yield of lactation

Five cows were excluded from analysis of the lactation yield because their lactations were shorter than 220 days (leading to n_{NC} = 12, n_{HC} = 10, n_{WC} = 11). Mean daily milk yield of lactation of HC (16.7 ± 3.7 kg) did not statistically differ from the other two treatments (P > 0.05). However, the effect size for the comparison with WC was with r = 0.31 medium. The mean daily milk yield of lactation was lower in WC (14.1 ± 2.6 kg) than NC (18.5 ± 2.1 kg, P = 0.015, r = 0.49). In general, mean daily milk yield of lactation increased with lactation number (F = 5.48, P = 0.026, r = 0.40, RSD = 2.642). Mean lactation number of the included animals was 4.0, 3.3 and 2.4 for NC, HC and WC treatments, respectively.

Milk fat and protein content

During 'nursing', fat content was about 1% point lower in CCC treatments than in NC (P < 0.05, r > 0.5), while during the later phases, fat contents of all treatments were similar (P > 0.05, Eta^2 < 0.1, Fig. 1B). During 'nursing', fat content of nursing cows was low during both, morning and afternoon milking with large effect size (P < 0.05, r < 0.5). There were no differences between HC and WC (Fig. 2B). The protein content of the treatments changed in different directions over the experimental phases. The protein content of NC cows was lowest during all phases (Fig. 1C). During 'nursing', protein content of HC was higher than of NC cows (P = 0.0085, r = 0.45) but there were no statistical differences between the other treatments. During 'in sight/milk feeding', still HC tended to higher protein contents than NC cows with a medium effect size (P = 0.0546, r = 0.35). Protein content of WC was higher than of NC cows during both phases after 'nursing' with a medium effect size (P < 0.05, r = 0.38–0.43).

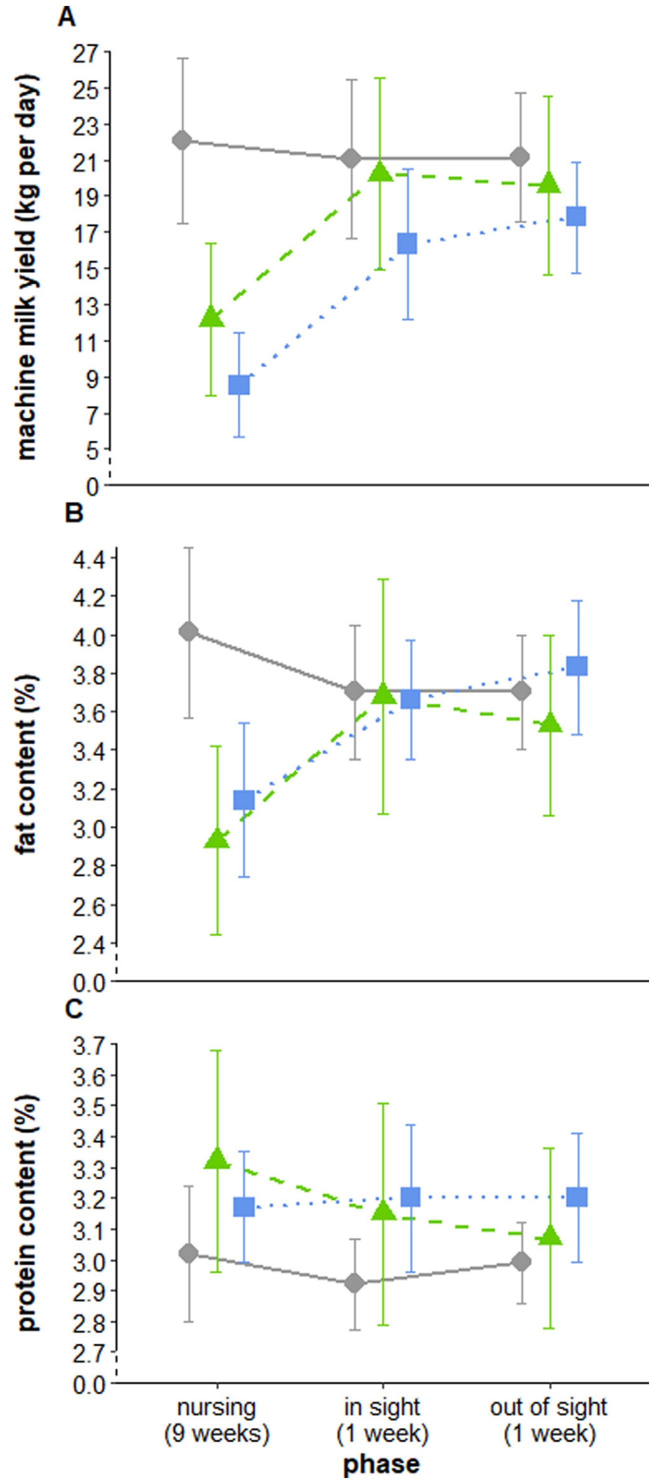

Fig. 1. Influence of no cow-calf contact (○, solid line, n = 14), half-day cow-calf contact (Δ, dashed line, n = 11) and whole-day cow-calf contact (□, dotted line, n = 13) on (A) machine milk yield (kg per day), (B) fat content (%) and (C) protein content (%) during different phases (mean ± SD) (*name of phases describe the procedure of cows with calf contact, only*).

Udder health

Udder-infections occurred only during the 1st 9 weeks *postpartum* and only in multiparous cows. Two WC and one NC cow had recurrent udder infections, which were treated as one incidence (Table 2). The numerically higher incidence of mastitis in WC cows

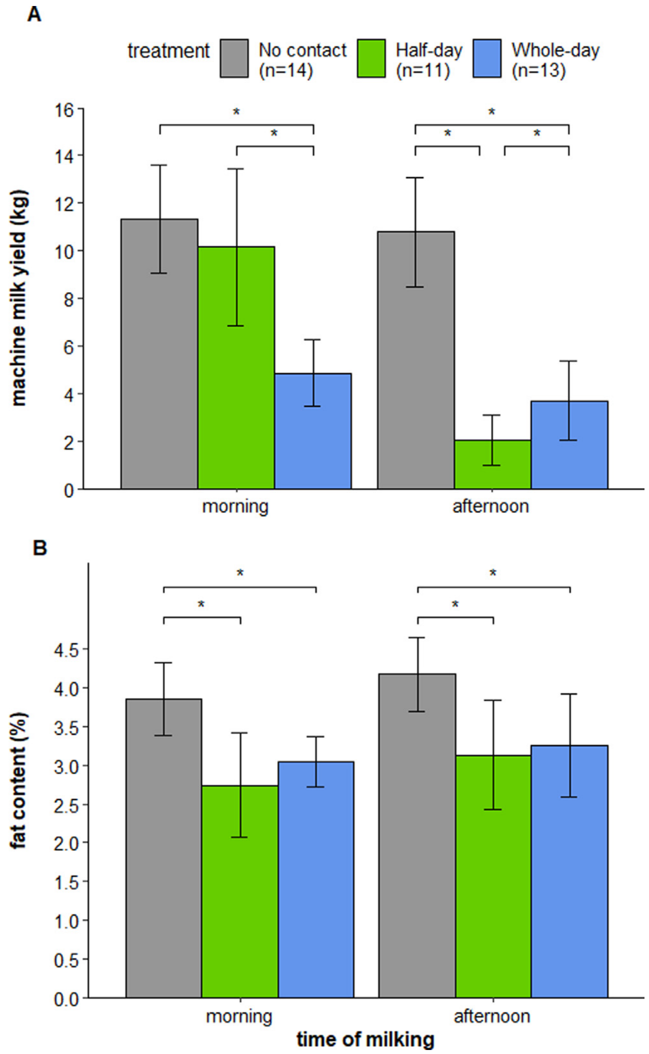

Fig. 2. Machine milk yield (kg) and fat content (%) of dairy cows at morning and afternoon milkings with no (n = 14), half-day (n = 11) or whole-day calf contact (n = 13) during 9 weeks *postpartum* (mean ± SD); * $P < 0.05$.

Table 2
Incidence of clinical mastitis in multiparous cows, percentage of milkings with somatic cell count > 100 000 cells per ml and somatic cell score (SCS, mean ± SD) of cows with no calf contact (NC: n = 4 primiparous, 10 multiparous), half-day (HC: n = 2 primiparous, 9 multiparous) or whole-day cow-calf contact (WC: n = 3 primiparous, 10 multiparous) during 11 weeks *postpartum* (nursing during the 1st 9 weeks).

Variable	Treatments	Primiparous	Multiparous
Incidence of clinical mastitis (number of cows (%))	NC	0 of 4	3 of 10 (30%)
	HC	0 of 2	3 of 9 (33%)
	WC	0 of 3	5 of 10 (50%)
SCC>100 000 cells/ml (% of milkings)	NC	33.96 ± 39.44	53.51 ± 41.69
	HC	6.47 ± 9.98	63.23 ± 35.47
	WC	9.79 ± 10.86	40.50 ± 32.83
SCS	NC	2.68 ± 1.45	3.32 ± 1.35
	HC	0.93 ± 0.51	3.83 ± 1.30
	WC	1.45 ± 0.55	2.81 ± 1.35

was not statistically significant ($P = 0.709$). Treatment did not have an influence on the percentage of milkings with SCC>100 000 cells per ml ($F = 1.19$, $P = 0.3167$, $Eta^2 = 0.06$, RSD = 18.202) and SCS ($F = 1.52$, $P = 0.2313$, $Eta^2 = 0.07$, RSD = 0.630, Table 2) over all phases. Primiparous cows had a significantly lower percentage of milkings with SCC > 100 000 cells per ml ($F = 6.78$, $P = 0.0131$, $Eta^2 = 0.15$) and lower SCS ($F = 9.35$, $P = 0.0041$, $Eta^2 = 0.20$, Table 2).

Calving interval

Eight, one and two cows of the NC, HC and WC treatment, respectively, left the farm before the next conception: Two NC and one HC primiparous cows were slaughtered for the farm shop (no health problems) and one NC first lactating cow was sold to another farm. Five multiparous NC and one WC cows were slaughtered due to udder health problems and one WC cow due to claw disease. In addition, two NC cows had an abnormally long period between calvings and were therefore excluded from the analysis. Data from 32 cows from the rest of the herd, which calved in 2011 and 2012, were added to the remaining four animals of the NC treatment for analysis. No statistical differences in calving intervals could be found for NC cows and the rest of the herd with a mean calving interval of 369 ± 41 days (n = 36) compared to 378 ± 42 days in HC (n = 10) and 363 ± 42 days in WC (n = 11) ($F = 0.34$, $P = 0.714$, RSD = 41.198).

Daily weight gain and BW of calves

Both HC and WC calves gained about 0.3 kg more weight per day during ‘nursing’ than NC calves ($P < 0.0001$, $r > 0.75$, Fig. 3), with no difference between HC and WC calves ($P = 0.9800$, $r = 0.04$, Fig. 3). After the ‘nursing’ phase ended, there was a growth check in both CCC treatments. Weight gain of HC was lower than of NC ($P < 0.0001$, $r = 0.69$) and WC calves ($P = 0.0476$, $r = 0.45$, Fig. 3). The variance in the HC treatment was high during this phase of ‘in sight/milk feeding’. WC calves then tended to grow more slowly than NC calves, with a medium effect size ($P = 0.0579$, $r = 0.44$). During ‘out of sight/weaning’ and ‘postweaning’, weight gain in

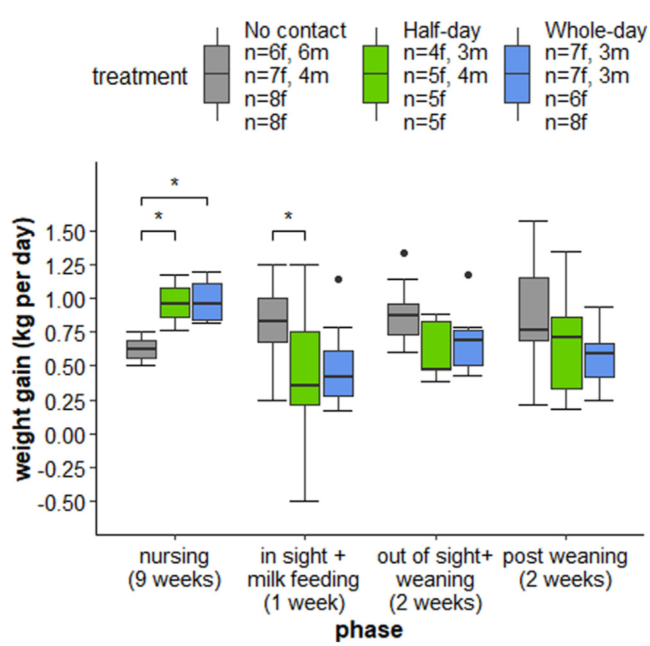

Fig. 3. Daily weight gain of female (f) and male (m) calves with no, half-day or whole-day cow-calf contact. Calves with no cow contact were nipple bucket fed during ‘nursing’ (6 l per day). All calves were nipple bucket fed during ‘in sight/milk feeding’ and ‘out of sight/weaning’ (6–2 l per day). Sample size varied due to missing or incorrect weighing and because male calves were sold after ‘in sight/milk feeding’ (*n* top–down relate to boxplots from left to right). Boxplot: lower whisker: minimum; lower end of the box: 25% quartile; line in the box: median; upper end of the box: 75% quartile; upper whisker: maximum; * $P < 0.05$.

both CCC treatments increased. They numerically still remained below the level of NC calves during these phases, but statistically, there were no differences between any treatments (P > 0.05, r < 0.20, Fig. 3). Two weeks after weaning the female calves of the NC treatment weighed less than HC (P = 0.0230, r = 0.63, Fig. 4) and WC calves (P = 0.0499, r = 0.49). The BW of both CCC treatments did not statistically differ (P = 0.6079, r = 0.14). Sex of calves did not have an influence on daily weight gain during 'nursing' (P = 0.183, r = 0.26) and 'in sight/milk feeding' (P = 0.961, r < 0.01). Afterwards, male calves were sold.

Discussion

Daily milk yield

Machine−collected milk yield in HC dams was lower than in NC cows during the nursing period, but there were no differences afterwards. During 'nursing', the numerical milk loss was on average 9.9 kg per day (45.0% of NC yield), which was lower than the milk loss in WC in the present study (13.5 kg per day or 62.0%). It must be considered that the NC-calves were fed with 6 kg of whole milk per day, which was the common feeding regime on this farm. This amount is now rated as too low; the difference of about 10 kg sellable milk per day and cow between NC and HC would be equivalent to updated feeding recommendations and similar to amounts calves drink when they are fed *ad libitum* (e.g. Ivemeyer et al., 2022). However, the feeding of milk replacer to conventional calves, or of waste milk may still be economically attractive, although the latter is not recommended, particularly when cows were treated with antibiotics (reviewed by Kertz et al., 2017).

When comparing average milk losses between CCC systems from different studies, beside contact duration, the breed and performance level must be considered. Therefore, in the following, differences are also expressed as percentages in relation to yields of non-nursing cows of the individual studies. The relative average loss of sellable milk in HC cows in our study (−9.9 kg per day or −45.0%) was in the lower range of other studies with whole-day contact, although the absolute milk loss was clearly lower (−41.8 to −68.9%, i.e. −12.2 to −25.7 kg per day, Zipp et al., 2018; Barth, 2020; Wenker et al., 2022; Neave et al., 2024a). This is due to the relatively low herd milk yield related to the breed and concentrate-free feeding in our experiment. Similarly, the relative milk loss of the WC cows in the current study was in the upper range of WC cows from the other studies, but the absolute loss was in the lower range (−13.5 kg per day or −62.0%). Compared to half-day contact systems in other investigations (night-time contact: Johnsen et al., 2015a: −35.1%, i.e. −14.2 kg; Barth, 2020: −43.2%, i.e. −12.4 kg; day-time contact: Nicolao et al., 2022: −42.4%, i.e. −11.4 kg; Neave et al., 2024a: −30%, i.e. −11.2 kg), the HC cows of this study had lower absolute milk losses, but comparable to higher relative losses.

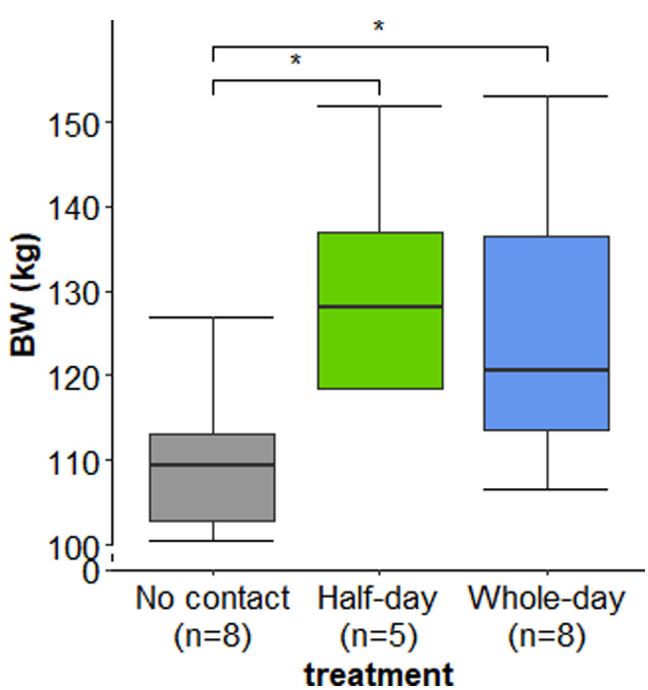

Fig. 4. BW of female calves with no, half-day or whole-day cow-calf contact at 14 weeks of life, 2 weeks after weaning. Boxplot: lower whisker: minimum; lower end of the box: 25% quartile; line in the box: median; upper end of the box: 75% quartile; upper whisker: maximum; * P < 0.05.

Short-time suckling systems mostly led to similar or even higher absolute milk losses compared to half-day CCC in the present study. However, the percentage of milk loss of half-day CCC in our study is higher compared to results from other authors for short-time contact after milking (−26.5–28.7%, i.e. −6.9 to −9.4 kg; Passillé et al., 2008; Mendoza et al., 2010; Nicolao et al. 2022), but lower compared to short-time contact before milking (−51.2–71.4%, i.e. −12.5 to −20.5 kg; Barth, 2020; Nicolao et al., 2022).

In the current study, the medium effect of on average 3.6 kg higher milk yield in HC versus WC contact resulted from higher milk yields during the morning milking, which is in line with other studies (Nicolao et al., 2022; Neave et al., 2024a). Afternoon milk yields in HC cows in the current study averaged 2.7 kg. Therefore, for low−yielding breeds in half-day CCC systems, milking only once per day might be considered as an option. Ospina Rios et al. (2023) already showed that this had no negative effect on udder health or milk yield of the lactation in a pasture-based system.

After 'nursing' ended, machine milk yields of cows that had reared their calves increased, although, conforming to results from Nicolao et al. (2022), the milk yield remained below the level of NC cows until the end of the recordings (12th week *postpartum*). However, considering the whole lactation, mean daily machine milk yields did not differ between NC and HC cows which is in accordance with results from Johnsen et al. (2015a), night-time contact). WC cows, on the other hand, still had moderately lower lactational milk yields than NC cows. No statistical difference between HC and WC was found, but the medium effect size with a considerable numerical difference suggests that the sample size should have been higher in order to reach clearer results. As calf growth was comparable in both CCC treatments, milk intake of calves was probably similar. A reason for the HC cows' higher milk yields might have been more complete udder emptying during morning milkings. More frequent udder emptying during early lactation stimulates milk synthesis and has carryover effects on the remainder of lactation (reviewed by Lyons et al., 2014). Thus, the frequent nursing combined with milking might cause an overall enhanced milk production in HC, which is also reported by Barth (2020). However, whole-day CCC might induce a negative feedback mechanism on milk secretion. Results from Barth (2020) for whole-day contact, but also for short-time contact before milking point into the same direction. Metz (1987) and Flower and Weary (2001), however, did not find differences in lactational milk yield between cows with no or whole-day calf contact, but in the latter studies, the cow-calf contact was only short (10–14 days), which may play a role.

However, when interpreting the milk yield during the experimental phases and across the lactation, it must also be considered that the treatments were no longer equally distributed with respect to the lactation numbers. Cows of the WC treatment had the lowest mean lactation number with a mean of 2.7 during the experimental phases and 2.4 when calculating lactation performance (NC = 3.6 and 4.0; HC = 3.1 and 3.3). Mutua and Haskell (2022) noted a higher milk yield in the parlour for cows with whole-day CCC starting at a lactation number of 3 compared to 1 or 2. Our results on lactation performance also show higher values at higher lactation numbers. The effect found by Mutua and Haskell (2022) that dams with female calves give more milk in the milking parlour than cows with male calves may somewhat offset the influence of lactation number during the suckling phase again (HC: six female, five male calves, WC: eight female, five male). Nevertheless, this disproportion complicates the interpretation of the data. Therefore, in subsequent experiments, attention should be paid to better randomisation of the treatment groups.

Milk composition

Independent from the extent of CCC, milk fat content of the dams during 'nursing' was about 1% point below the values of non-nursing animals. This is in line with several other studies (e.g. Boden and Leaver, 1994; Mendoza et al., 2010; Barth, 2020). The alveolar milk fraction has the highest fat content and remains in the udder when milk ejection problems occur (Ontsouka et al., 2003). The lower fat content in the HC treatment during morning and afternoon milkings (Fig. 2) suggests that there were still milk ejection problems even in the morning. At the same time, high variation in morning milk yield and fat content reflect high individual differences. This might provide a starting point for selective breeding towards improved milkability of dams. In accordance with other studies, fat content after separation did not differ between treatments (Mendoza et al., 2010; Barth, 2020; Nicolao et al., 2022: trial 2). Separation of calves and cows was conducted on Wednesdays. As the next milk samples were taken on Monday, we cannot exclude a possible influence of separation on milk composition, e.g. a drop in milk fat, during the 1st 4 days after separation.

Protein contents were in general low. Only HC cows during 'nursing' reached the average herd-level of the year before, which was 3.33%. Reason for the low protein content is likely a low energy content in the ration (e.g. Gross et al., 2011). Nursing cows had numerically higher protein contents than the NC treatment, which has also been found by other researchers (Boden and Leaver, 1994; Barth, 2020; Ospina Rios et al., 2023) independent from the CCC system. However, in other studies, no effect or even a lower protein content due to nursing have been reported (reviewed by Johnsen et al., 2016). It is unclear why the protein content of HC animals dropped after the 'nursing' phase. Currently, no information on involved proteins or possible physiological mechanisms are available.

Udder health and calving interval

There were no differences in udder health between treatments, although the low sample size and consequently low power of testing need to be considered. Three cows in the HC and the NC treatment each, and five cows in the WC treatment had clinical mastitis, which is an animal welfare problem. In 31–56% of milkings, SCC was above 100 000 cells per ml. In general, these are suboptimal results that are, however, on a comparable level to results from Ivemeyer et al. (2018) for 41 German organic farms (with 51.0 ± 12.6% of milkings > 100 000 cells per ml). Numerous studies found that suckling combined with milking did not negatively affect udder health or even improved it (Johnsen et al., 2016; Sørby et al., 2024). Barth (2020) found a slightly increased SCC in nursing dams, which may be a sign that teats were strained by the combination of suckling and milking. The generally higher SCS during nursing than during the other phases might be due to high SCS after calving, which is not necessarily a sign of an infection and lasts up to 2 weeks (Dohoo and Meek, 1982).

The calving interval was not influenced by CCC, although again low sample sizes must be considered. While anoestrus can be prolonged in nursing cows (reviewed by Kälber and Barth, 2014), it has been found that the calving-conception interval is not impaired or is even shorter in CCC systems (reviewed by Johnsen et al., 2016). This should result in similar calving intervals between groups, as confirmed in the current study. As more cows of the NC group were slaughtered before the next conception due to udder health problems (5 NC, 1 WC) and no cow was slaughtered or culled for fertility reasons, no risk of CCC on udder health or fertility was apparent in the long term.

Daily weight gain and live weight of calves

The extent of weight gain advantage in dam–reared compared to calves without CCC depends on the amount of milk provided to the calves fed by bucket or automatic milk feeder. With 6 l milk per day (15.7–6.2% of mean BW), the feeding regime in this study was relatively restrictive. Median growth rates of NC calves during the first 9 weeks *postpartum* did not reach the target value of at least 0.7 kg per day (Hynd, 2019, p. 236). Feeding only 6 l milk per day was common practice on the research farm in 2011–2012 and still reflects feeding management on some commercial farms (Ivemeyer et al., 2022). Therefore, it is no surprise that HC and WC calves gained more weight than NC calves. This is in line with numerous studies that compared CCC calves with calves fed restricted quantities of up to 8 l (e.g. Flower and Weary, 2001; Roth et al., 2009; Ospina Rios et al., 2023). However, calves without CCC receiving 10–12 l or having *ad libitum* milk access had comparable or even higher weight gains than WC (Veissier et al., 2013; Bertelsen and Jensen, 2023b) and HC calves (Veissier et al., 2013; Johnsen et al., 2015a; Nicolao et al., 2022; Bertelsen and Jensen, 2023b).

A main point of interest in the current study is the lack of a significant difference in weight gain between WC and HC calves during 'nursing', which confirms the results of other studies (Veissier et al., 2013; Bertelsen and Jensen, 2023b). However, after 'nursing' stopped, there was a growth check in all CCC calves, which is in line with other findings (reviewed by Johnsen et al., 2016; Nicolao et al., 2022; Bertelsen and Jensen, 2023b). During 'in sight/milk feeding', CCC calves had to learn to drink milk from nipple buckets and possibly obtained less milk than before. Besides this, separation stress may have affected their growth. The CCC duration of 9 weeks in the current study is categorised as moderate by Eriksson et al. (2022). In their survey, farmers with moderate CCC reported a higher percentage that they had problems with weight loss of calves after separation than farmers, who allowed short (7–28 d) or long cow-calf contact (> 90 d). It has been suggested that calves at the age of 29–90 d may have more problems to change their feeding habits (Eriksson et al., 2022).

It is well established that feeding lower milk amounts to calves stimulates higher concentrate intake (e.g. Ivemeyer et al., 2022; Bertelsen and Jensen, 2023b). This may account for the lack of growth check in NC calves in our study and underlines the importance of more sophisticated weaning methods for calves fed higher milk amounts, with (e.g. Bertelsen and Jensen, 2023a) or without CCC (e.g. Ivemeyer et al., 2022). We expected that locking the HC calves in the calf creep between afternoon and morning milking may stimulate their intake of solid feed compared to WC and would lead to lower weight losses in HC compared to WC calves as found in other studies (Veissier et al., 2013; Roadknight et al., 2022; Bertelsen and Jensen, 2023b). However, in our study, HC calves gained even less weight than WC during 'in sight/milk feeding', which is difficult to explain, but the low sample size and high variation again need to be considered. Recent findings suggest an impaired welfare of animals in half-day CCC systems compared to whole-day contact (Roadknight et al., 2022; Bertelsen and

Jensen, 2023a; Neave et al., 2024b), which might be a reason for a more severe growth check after separation of HC calves in our study. Roadknight et al. (2022) observed more restless behaviour of the half-day contact calves after daily separation, and of calves and cows before reunion compared to animals with whole-day contact which were separated for milking only. This could indicate that the separation was perceived as aversive for the half-day contact animals, as maternal bonding was shown to be comparable between whole-day and half-day cow-calf contact (Jensen et al., 2024). Neave et al. (2024b) found more pessimistic decisions in a visual bias judgement test in dams with half-day contact than in cows with whole-day or without calf contact. It was concluded that this indicates a negative emotional state of the animals and may be caused by the repeated cow-calf separation in the half-day system (Neave et al., 2024b). Half-day contact cows avoided nursing more often and showed more agonistic behaviour during suckling attempts when they were reunited with their calves after milking, compared to whole-day contact cows (Roadknight et al., 2022). Although these behaviours were not systematically monitored as part of the recent study, our informal observations are consistent with this result. Potential discomfort of the dams during nursing after re-entering the barn may be due to the low udder filling combined with the calves being hungry after the half-day separation period. This was also suggested by Bertelsen and Jensen (2023b), who in addition observed more half-day contact calves suckling alien cows after the separation period. Roadknight et al. (2022), however, did not find differences in milk cortisol level between half-day and whole-day contact cows. Altogether this indicates some negative impact of half-day contact on animal welfare, the extent of which needs to be further investigated and should be considered in the evaluation of the system.

During the next phase ‘out of sight/weaning’ in our study, differences in weight gain between all treatments were only numerical. Nevertheless, BW 2 weeks after weaning was on average still 11–19 kg higher in both CCC treatments than in NC ($P < 0.05$, $r > 0.3$). However, when these animals were weighted after their first calving, there were no differences between treatments any longer. However, the low sample size must be considered (Zipp and Knierim, 2020).

Half-day CCC during the day is a promising suckling system in terms of limiting the loss of sellable milk over the whole lactation while securing a similarly high weight gain of calves and BW after weaning compared to the whole-day CCC system. At the same time, it allows increased cow-calf interaction compared to short-time contact systems. Nevertheless, the lower milk fat content during nursing points at a disturbed milk ejection during the nursing period in both CCC groups. Also, the calves’ growth check directly after separation needs further investigation. It is unclear why it was more severe in HC than in WC calves. No effects on udder health and calving interval were detected, but udder health was suboptimal in general. Possible impairments of welfare due to repeated separation need further attention and should be part of future research.

Supplementary material

Supplementary material to this article can be found online at https://doi.org/10.1016/j.animal.2024.101318.

Ethics approval

The experimental procedure consisted of common husbandry practices and data were recorded by non-invasive means. Cow and calves were reared and kept for production for human consumption according to national law and guidelines, and not for experimental purposes. Therefore, ethical approval was waived for this study, as approved by the Designated Veterinarian for Institutional Animal Care at the University of Kassel. The study was conducted in accordance with the German Animal Protection Act (implementing the Directive 2010/63/EU on the protection of animals used for scientific purposes) and the Guidelines for the Ethical Treatment of Animals in Applied Animal Behaviour and Welfare Research of the International Society for Applied Ethology.

Data and model availability statement

None of the data were deposited in an official repository. The data that support the study findings are available from authors upon request.

Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the authors used DeepL in order to translate some sentences or words from German to English language and vice versa. After using this tool, the authors reviewed and edited the content as needed and took full responsibility for the content of the publication.

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CRediT authorship contribution statement

K.A. Zipp: Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **U. Knierim:** Writing – review & editing, Supervision, Methodology, Conceptualization.

Declaration of interest

None.

Acknowledgements

We thank the staff of the research farm Hessische Staatsdomäne Frankenhausen especially Gerber van Vliet, Helena Karbstein, Martina Wetzel, Tina von Roedern, Lisa Born, Florian Thaller, Janne Gleitz, Christian Krutzinna, Marco Tamm, Sebastian Hofmann and Jonas Schlüter. We are also very grateful for free milk analyses from Hessischer Verband für Leistungs- und Qualitätsprüfungen in der Tierzucht e.V., especially to Dominik Neufang, Heino Schmitz and Hans-Jürgen Betz. Further thanks to Tina von Roedern for checking the English, Silvia Ivemeyer, Kerstin Barth and Jan Brinkmann for fruitful discussions. For statistical assistance, we would like to thank Eike Rommelfanger and Yannick Rzehak. We acknowledge that part of the data presented in this article has been included in a Master (Rzehak, 2014) and PhD thesis (Zipp, 2018); the data have also been published in a different form as two conference contributions (Zipp et al., 2017a; Zipp et al., 2017b).

Financial support statement

The University of Kassel provided the first author with a dissertation scholarship (no grant number). Hessischer Verband für Leistungs- und Qualitätsprüfungen in der Tierzucht e.V. provided the analysis of milk content for free (no grant number).

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