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Dam–calf contact rearing in Switzerland: Aspects of management and milking

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ABSTRACT

Cow–calf contact (CCC) rearing is becoming an increasingly popular alternative to the common practice of early separation of cow and calf in dairy management. Milkability can be impaired in nursing cows, which contributes to the loss of machine milk yield caused by calf intake, especially in pure dam–calf contact (DCC) systems. The aims of this study were (1) to describe the current status quo of DCC rearing regarding management and milking and (2) to evaluate the effects of DCC (suckling and milking vs. milking alone) and the effects of different types of DCC on milkability parameters, teat condition, and behavior during milking on Swiss DCC farms. By means of 17 telephone interviews with DCC farmers, we collected data on DCC management, housing, separation and weaning processes, milking procedures and techniques, and perceived milkability problems. Subsequently, we collected data on 10 of the interviewed DCC farms (183 cows): 4 DCC farms with a whole-day contact (WDC) system, 3 farms with DCC before milking (CBM), and 3 farms with DCC after milking (CAM). Five farms on which calves had no contact with dams were chosen as reference farms (178 cows). Using a milk flow meter, the occurrence of ejection disorders, bimodality of the milk flow curve, machine milk yield, duration of the decline phase, and duration of prestimulation were measured. The average mouthpiece chamber vacuum during the main milking phase and hind leg activity during milking were measured using a pressure sensor and an accelerometer, respectively. After cluster removal, the teat condition was evaluated, and a stripping milk sample was taken for fat content analysis. The interview results revealed that 8 of the 17 farms surveyed had a WDC system, and 2 farms operated a daytime DCC system. Contact before milking was applied by 3 farms, and 3 farms allowed CAM. On one farm, calves had access to dams 3 times a day. A great diversity in cow–calf management was found. In the on-farm data collection, 20 milkings of a total of 701 milkings examined met the criteria for a clear ejection disorder, with 17 of these observations occurring on WDC farms and none on reference farms. The stripping milk fat content was lower in nursing cows, indicating a lower degree of udder emptying. Machine milk yield was higher in nursing CAM cows than in nursing WDC and CBM cows. Farm types did not differ regarding teat condition, hind leg activity, or the occurrence of bimodal milk flow curves. In conclusion, the large variation in individual management approaches to DCC rearing even within DCC types, such as calf housing or cow breeds, implies caution when interpreting results. Contact after milking may be the system most beneficial for some productivity parameters, but adequate calf supply must be ensured. Higher amounts of milk remaining in the udder after cluster removal indicate that nursing can affect milkability, but future research should consider the effects of udder filling before milking to better interpret the fat content of stripping milk.
Key words: cow–calf contact, milk fat in stripping milk, teat condition, hind leg activity

INTRODUCTION

In recent years, an increasing number of dairy farmers have started to extend cow–calf contact (**CCC**) using dams or foster cows with the intention of enabling higher animal welfare for cows and calves (Wagenaar and Langhout, 2007; Barth, 2020; Johanssen et al., 2023). Dam–calf contact (**DCC**) rearing allows the formation of a mother-young bond (Kent, 2020), natural suckling, and affiliative behaviors between the dam and calf (von Keyserlingk and Weary, 2007). Therefore, it represents the most natural form of calf rearing in dairy production. By contrast, in pure foster cow systems, calves benefit from the opportunity to suckle an udder and interact with adult conspecifics, while dams that are not used for calf fostering are milked without any contact with calves (Sirovnik et al., 2020; Wieczorreck and Hillmann, 2022). In practice, most farms rear the calves with dams or oper-

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ate a mixed system with dams and foster cows (Eriksson et al., 2022).

In DCC systems, cows are usually milked twice or sometimes once a day. The average machine milk yield is reduced because of the calves' milk intake (Barth, 2020), and individual variation of machine milk yield between dams is high (Sørby et al., 2024). In addition to a lower machine milk yield, poor milkability has been reported in DCC systems (de Passillé et al., 2008; Mendoza et al., 2010; Zipp et al., 2018; Barth, 2020). "Poor milkability" can be considered a reduction in machine milk yield due to incomplete milk removal, incomplete milk let-down, or a milk ejection disorder, which are based on dysfunctions of the udder or an inappropriate milking technique. Complete milk removal (or good milkability) requires a healthy udder tissue (Querengässer et al., 2002) and a functioning milk ejection reflex, in which oxytocin (**OT**) is released by the posterior pituitary in response to tactile teat skin stimulation. In the mammary gland, OT causes a contraction of myoepithelial cells surrounding the alveoli, which results in milk expression into the cistern. Oxytocin levels must continuously be elevated throughout the milking process to cause full milk let-down (Bruckmaier and Blum, 1998). Poor milkability may be caused by insufficient activation and maintenance of the milk ejection reflex, resulting in low plasma OT levels during milking. It has been demonstrated that in nursing cows, suckling is a more potential stimulus for OT release than milking (Bar-Peled et al., 1995; Tančin et al., 2001a; de Passillé et al., 2008), but the underlying mechanisms are unclear. At the mammary level, long-term treatment with exogenous OT causes a downregulation of OT receptors in the mammary gland, resulting in impaired milk let-down despite sufficient OT release (Bruckmaier, 2003). Another explanation for poor milkability in nursing cows could be the low degree of udder filling at the start of milking. A low degree of udder filling can lead to a delay until the start of milk ejection and result in a bimodal milk flow curve (Bruckmaier and Hilger, 2001), which reflects an interruption of the milk flow between the milking of the cisternal and the alveolar fraction (the cistern is emptied before milk is released from the alveolar compartment; Bruckmaier and Blum, 1996; Dodenhoff et al., 1999). Bimodality is associated with the duration of prestimulation and can be related to lower machine milk yields (Sandrucci et al., 2007; Samoré et al., 2011; Fernandes et al., 2023).

The consequences of incomplete milk removal include higher amounts of stripping milk causing a backflow of cisternal milk to the alveoli and thus faster udder filling, which results in a lower machine milk yield over time (Albaaj et al., 2018; Kuehnl et al., 2019). A bimodal milk flow causes the teat cup to climb at the start of milking. Thereby, the vacuum in the liner mouthpiece chamber increases and remains high during the entire milking process (Erskine et al., 2019), which over time can lead to poor teat condition (Odorčić et al., 2019; Vierbauch et al., 2021). An increased frequency of hind leg kicking has previously been observed at a higher mouthpiece chamber vacuum (Meyer et al., 2021) or with teat lesions (Rousing et al., 2004). Thus, hind leg activity during udder preparation and milking is a valid parameter for identifying mental or physical discomfort in cows (cited from Meyer et al., 2021).

The effect of calf contact on milkability may vary depending on the type of DCC. Wenker et al. (2022) compared cows with whole-day DCC to cows with no or partial DCC (calf in an adjacent pen, allowing physical contact but no suckling). Lower machine milk yields and milk fat contents in cows with whole-day DCC compared with other systems were found, likely caused by ineffective milk ejection due to suckling (Barth, 2020). However, the effects of different daily contact durations and the timing of suckling and milking in different on-farm systems are unclear.

Lower machine milk yield and poor milkability have been identified as 2 challenging issues faced by DCC farmers (Johnsen et al., 2016; Bertelsen and Vaarst, 2023; Vaarst and Christiansen, 2023). In this study, we aimed to examine the current status quo regarding management and milking of DCC farms in Switzerland by means of phone interviews. In a subsequent on-farm data collection we hypothesized that (a) nursing in general and (b) different types of DCC affect milkability parameters, cow behavior during milking and teat condition.

MATERIALS AND METHODS

Ethical approval to conduct this study was obtained from the Veterinary Office of the Canton of Thurgau in Switzerland (approval number TG09/2021). All methodologies were performed in accordance with relevant national and cantonal guidelines and regulations.

Experimental Design

In a first step, 17 DCC farms registered in the database of the Centre for Dam–Calf Contact Rearing (Birmensdorf, Switzerland) were interviewed about farm characteristics and management as well as the occurrence and details of poor milkability in January 2022.

In a second step, on-farm data were collected on 10 of the interviewed DCC farms during one evening milking and the subsequent morning milking per farm. Additionally, the same dataset was collected on 5 dairy farms serving as reference farms where cows and calves were separated within 24 h after birth.

Interviews

In November 2021, all 19 farms registered in the database of the Centre for Dam–Calf Contact Rearing (Birmensdorf, Switzerland) were asked to participate in the interview study by email. The database does not include farms operating a foster cow system or switching calves from the dam to a foster cow before the age of 3 mo. Approval for a semi-structured phone interview was obtained from 18 of the 19 farmers. One of the 18 contacted farmers still had not changed their system to DCC and was therefore not included in the survey. The remaining 17 farms were interviewed by telephone concerning the topics shown in Table 1 by the second author. The questionnaire (Supplement Material S1, see Notes) was developed in collaboration with scientists of the Centre for Dam-Calf Contact Rearing (Birmensdorf, Switzerland). Before each interview, respondents signed a written consent form that informed them about their right to quit the interview at any time, to skip questions, and that collected data would not be given to third parties and would be published in an anonymized form. During each phone interview, the farmers' answers were recorded in a separate file. After completing all interviews, a table summarizing the answers to all questions was created.

Farms and Animals

Fourteen of the 17 farms were interested in participating in the on-farm data collection. Four of these farms were excluded because they milked with milking buckets. The 10 remaining farms were included in the on-farm data collection: 4 farms with whole-day DCC (**WDC**) and 3 farms each with twice-daily short-time contact before (**CBM**) and after milking (**CAM**) were selected. No farm with daytime or nighttime DCC was visited, as only 2 farms, both of which had low animal numbers, were available in our sample. Whole-day DCC was defined as a 24-h contact except during the milking time. Daytime or nighttime contact was defined as DCC during the daytime or nighttime (de Oliveira et al., 2020). Contact before milking and CAM were defined as DCC restricted to a maximum of 4 h before or after milking. Across all included farms, 87 cows were kept in systems with WDC, 55 cows with CBM, and 40 cows with CAM. On average, the 10 selected DCC farms had 23 cows (range: 12–38) and 18 milked cows at the time of the study. The average machine milk yield of the 10 DCC farms was 6,000 kg (range: 5,000–8,500 kg).

In addition, 5 dairy farms with no-contact rearing were visited to allow for comparison with the non-nursing cows of the DCC farms. To find comparable reference farms, we asked local milking machine dealers for farms where high performance was not the main focus. The selected farms had similar annual machine milk yields to the DCC farms and the ratio of tiestalls versus freestalls among reference farms was the same as among DCC farms. Reference farms had an average of 40 dairy cows (range: 26–49) and 36 milked cows at the time of the study. These farms were used to assess comparability across non-nursing cows of the DCC farms and were not included in the statistical models.

In total, 182 milked cows from DCC farms and 180 milked cows from reference farms were included in the study. On all DCC farms, there were cows that nursed their calf ("nursing cows") as well as cows that did not nurse their calf, for example, cows after weaning, separation, or calf death ("non-nursing cows"). Nursing and non-nursing cows were maintained in the same herd under the same conditions on all farms. The number of nursing and non-nursing animals per farm, as well as the mean lactation number and DIM per study group, are presented in Table 2.

The farms were visited between February and mid-April 2022 during an evening milking and the consecutive morning milking. To increase the sample size, DCC farms were visited when the highest number of dam–calf pairs was available.

Data Recording and Processing

Observation of DCC. To determine the time lag between the last suckling event and milking, 2 researchers visually observed the herd and recorded the occurrence

Table 1. Topics and details explored during the telephone interviews with 17 farmers

Topic	Details inquired
Farm characteristics	Herd size; breed; production system (conventional, organic, label); housing system (freestall or tiestall); calf housing; calving period; feeding; general cow and calf health
Cow–calf management	Reason for adopting a dam–calf contact (DCC) system; calving site; duration in calving pen; DCC system (whole day, daytime or nighttime, twice daily); estimated amount of suckled milk
Weaning	Age; BW; abrupt vs. gradually; differences between male and female calves; tactile contact during weaning; use of nose flaps
Milking	Frequency; milking times; milking system (bucket, pipe, parlor); vacuum level; presence of a milk meter; type of prestimulation; type of cluster removal (automatic vs. manual); teat cleaning technique; recent changes in milking techniques
Milkability problems	Estimated occurrence of poor milkability; number of cows affected; lactation stage and number of affected cows; measures taken; milk fat content

Table 2. Overview of farms visited for data collection including farm type (reference; WDC = whole-day contact; CBM = contact before milking; CAM = contact after milking), number of non-nursing and nursing cows, number of milked cows, lactation numbers, and DIM assessed in the on-farm data collection

ID	Farm type	Calf	No. of milked cows	Lactation number mean (range)	DIM mean (range)
C1	Referent	Non-nursing	50	2.9 (1–7)	189.7 (18–418)
C2	Referent	Non-nursing	31	3.3 (1–8)	204.6 (25–797)
C3	Referent	Non-nursing	42	3.7 (1–11)	132.5 (4–799)
C4	Referent	Non-nursing	25	3.8 (1–8)	130.9 (8–461)
C5	Referent	Non-nursing	32	4.0 (1–4)	213.5 (9–512)
1	WDC	Non-nursing	15	2.7 (1–5)	205.0 (21–308)
		Nursing	10	2.6 (1–7)	102.7 (23–160)
2	WDC	Non-nursing	29	4.0 (1–9)	160.4 (25–337)
		Nursing	3	5.0 (4–7)	13.7 (11–16)
3	WDC	Non-nursing	10	3.7 (1–8)	269.4 (93–482)
		Nursing	7	3.2 (2–6)	57.7 (18–94)
4	WDC	Non-nursing	7	3.9 (1–7)	298.9 (143–405)
		Nursing	6	3.5 (2–5)	33.3 (13–70)
5	CBM	Non-nursing	24	4.8 (1–10)	192.0 (41–511)
		Nursing	5	7.0 (2–12)	59.4 (9–138)
6	CBM	Non-nursing	6	2.2 (1–4)	106.8 (23–159)
		Nursing	9	4.6 (4–6)	41.5 (1–104)
7	CBM	Non-nursing	3	3.3 (3–4)	27.7 (15–41)
		Nursing	8	4.6 (2–8)	32.8 (11–52)
8	CAM	Non-nursing	3	3.3 (2–5)	301.7 (105–495)
		Nursing	5	3.3 (2–5)	100.8 (69–138)
9	CAM	Non-nursing	4	2.3 (1–3)	155.5 (96–249)
		Nursing	12	2.9 (1–5)	76.4 (5–254)
10	CAM	Non-nursing	9	1.8 (1–2)	265.3 (25–489)
		Nursing	7	1.9 (1–4)	21.4 (7–39)
Overall	Referent	Non-nursing	36.0	3.5	174.2
	WDC	Non-nursing	15.3	3.6	233.4
		Nursing	6.5	3.6	51.8
	CBM	Non-nursing	11.0	3.4	108.8
		Nursing	7.3	5.4	44.6
	CAM	Non-nursing	5.3	2.5	240.8
		Nursing	8.0	2.7	66.2

and duration of suckling events on the first day of the farm visit. Allosuckling events were included. On the WDC farms, observation was carried out during the 4 h before milking started. On the CBM farms, the observations started with the farm-individual time of the reunion of calves and cows. On the CAM farms and on the reference farms, calves did not have the opportunity to suckle before milking, and no observations were carried out.

Stripping Milk Fat Content. A bulk sample of the stripping milk of the 4 quarters was taken manually after removal of the milking cluster during the evening milking on the first day of the farm visit. The samples were sent to the laboratory Swisslab (Suisselab AG, Zollikofen, Switzerland), where the fat content was analyzed by infrared spectrometry. As the fat content of milk physiologically increases during the course of milking (Ontsouka et al., 2003), incomplete udder emptying results in lower fat levels in stripping milk (Barth, 2020).

Milkability Parameters. During the evening and the subsequent morning milking, various parameters of milkability were continuously recorded with the milk meter LactoCorder (WMB AG, Berneck, Switzerland). The LactoCorders were connected to the milking cluster and attached to the edge of the milking parlor or the milk pipe. Using the LactoCorder system, the machine milk yield, the average milk flow during the main milking phase, the length of the ascent, the plateau and descent phase, and the time needed to reach a milk flow of 0.5 kg/min were recorded automatically. Measurement bases for milkability parameters used by the LactoCorders are described in detail in Steidle et al. (2000).

Depending on the farm and the presence of an automatic prestimulation, the duration of the prestimulation was measured either with a timer or with the LactoCorder. For reliability purposes, both techniques were used at the same time in 25 animals on 2 farms. The values corresponded well, with a maximum difference of 12 s. Prestimulation was defined as the time from the first contact with the udder until the attachment of the last teat cup. If the milking system included automatic prestimulation, the duration of the automatic prestimulation was added to the prestimulation.

In addition to the parameters of milkability, the LactoCorder software identifies bimodal milk flow curves (for a detailed description, see Steidle et al., 2000). Furthermore, the occurrence of clear ejection disorders, which was characterized as a machine milk yield of less than 1 kg and an interval between suckling and milking of more than 1 h, was recorded based on the machine milk yield data of the LactoCorder and our animal observations. Assuming an average machine milk yield of 10 kg per milking of a full udder, 2 kg (~20%) represents the cisternal fraction (Pfeilsticker et al., 1996; Ayadi et al., 2004), which is available for milk removal without activation of the milk ejection reflex (Bruckmaier and Blum, 1998). As we expected udders to be partly emptied due to calf suckling, we lowered the threshold to 1 kg to avoid overestimation of ejection disorders. An interval of 1 h was assumed to ensure the presence of at least 1 kg of milk in the udder, due to the relatively constant rate of milk secretion (Elliott et al., 1960; Wheelock et al., 1966).

Hind Leg Activity During Milking. Accelerometers of type MSR145 data loggers (MSR145B15 [size: 27 × 16 × 53 mm, weight: 20 g], MSR Electronics GmbH, Seuzach, Switzerland) were installed at the base of up to 10 milking clusters per farm to indirectly measure hind leg activity during the evening milking and the following morning milking for each cow at a frequency of 10 Hz. The use of accelerometers allowed for the assessment of restlessness by measuring the activity of the hind legs during milking (Raoult et al., 2021). The acceleration data were converted into the number of hind leg movement phases per minute of milking, using the evaluation software “Milking Time Test” (InnoClever GmbH, Liestal, Switzerland). Although Raoult et al. (2021) set a threshold of 0.13 g to determine whether a movement phase was caused by stepping or kicking of the cow, the threshold for this study was set at 0.25 g due to pre-tests with diverse clusters and pulsation types on the different farms, resulting in better accuracy.

Vacuum in the Liner Mouthpiece Chamber. To measure the vacuum level in the mouthpiece chamber, a second MSR145 data logger (MSR145B15 [size: 27 × 16 × 53 mm, weight: 20 g], MSR Electronics GmbH, Seuzach, Switzerland) with a built-in pressure sensor was attached to the front right teat cup and connected to the mouthpiece chamber on up to 8 milking clusters per farm. On farms with a pipeline milking system in tiestalls, all clusters were equipped with loggers, as no more than 4 clusters were used per farm. In milking parlors with more than 8 milking places, the loggers were attached to the first 8 clusters conveniently, but cows entered the milking parlor randomly.

The data logger was installed on the front teat cup due to the different morphology of the front and rear quarters. The hind quarters are slightly more developed and therefore produce more milk (Tančin et al., 2006). Furthermore, calves prefer to suckle on the front quarters (Fröberg et al., 2008), resulting in a shorter milking time of the front quarters and, thus, a longer overmilking phase, which is critical for udder health. The loggers recorded the vacuum level in the mouthpiece chamber at a frequency of 10 Hz during the evening milking and the following morning milking. The logger data were imported and processed using the software “Milking Time Test” (InnoClever GmbH, Liestal, Switzerland).

Teat Bonitation. The condition of the right front teat of the cows, where the vacuum in the mouthpiece chamber was measured, was assessed by one person within 60 s after removal of the milking cluster at the end of the evening milking. The color of the teat (pink, red, or blue), swellings at the teat base, and teat end congestion were recorded in accordance with the guidelines for evaluating the teat skin condition of the National Mastitis Council (NMC, 2007).

Statistical Analysis

R version 4.2.0 (R Core Team, 2021) was used to perform the statistical analysis, using generalized linear mixed-effects models (**GLMER**) and linear mixed-effects models (**LMER**) with the lme4 package (Bates et al., 2015). Residuals and outcome variables of LMER were examined graphically to verify compliance with the statistical assumptions of normal distribution and homoscedasticity. The model assumptions of GLMER were assessed using the DHARMa package (Hartig, 2022). Using stepwise backward reduction, the final models were obtained with a *P*-value of >0.05 as an exclusion criterion. *P*-values less than 0.1 were taken into account and considered a trend. The *P*-values of the fixed effects were extracted using the parametric bootstrap method for model comparison (package pbkrtest; Halekoh and Hojsgaard, 2014).

To reduce the number of outcome variables, correlations between outcome variables were tested with the ‘psych’ package (Revelle, 2023), and study outcomes using principal component analysis to identify milking parameters of interest (Gómez et al., 2022) were considered. The selected outcome variables were the occurrence of clear ejection disorders (binomial GLMER; <1 kg milk and no suckling during >1 h before milking), stripping milk fat content (LMER, continuous; evening milking only), machine milk yield (LMER, continuous), duration of the decline phase (LMER, continuous), occurrence of bimodality (binomial GLMER), number of hind leg activity phases per minute of milking (LMER, continuous), and swellings at the teat base after removal of the milking cluster (binomial GLMER; evening milking only).

Observations were grouped into 2 categories: observations of cows that nursed their calf (“nursing cows”) were distinguished from observations of gestating cows, cows after weaning, separation, or calf death ("non-nursing cows"). We initially assessed whether non-nursing cows were comparable across systems with regard to the selected outcome variables. For this purpose, we modeled data for all non-nursing cows, including farm type (no contact, WDC, CBM, CAM; experimental unit: farm) as a fixed effect, as well as DIM and lactation number (first or subsequent lactation) as covariates. As a random effect, cow nested in farm was used in the model. For stripping milk fat content and swellings at the teat base, the farm was included as a random effect, as these variables were recorded during the evening milkings only.

After confirming that non-nursing cows were comparable across systems, the subsequent analysis focused on data from DCC farms only; that is, reference farms were not included. Statistical models included the DCC type at the farm level (WDC, CBM, or CAM; experimental unit: farm), nursing versus non-nursing (experimental unit: cow), duration of prestimulation (experimental unit: cow), and average mouthpiece chamber vacuum during the main milking phase (experimental unit: cow). In addition, the interaction between the type of DCC and nursing versus non-nursing (experimental unit: cow) was included in the model as a fixed effect. The interval between the last suckling and milking was not included in the model, because this interval was closely linked to DCC type. Again, DIM and lactation number were included as covariates. As a random effect, the cow nested in the farm was included in the model. Milking time (morning or evening) was included as a crossed random effect in the model for the outcome variables measured during both milkings.

While the observational unit was always the cow, for between farm comparisons, the farm was considered the experimental unit because DCC type differed between farms. In contrast, given that on all farms both nursing and non-nursing cows were observed within the same herd, the cow was considered the experimental unit for the comparison of non-nursing versus nursing cows as well as interaction with farm type (Bello et al., 2016).

RESULTS

Survey: Current Status of Management and Milking on DCC Farms in Switzerland

Tables 3 and 4 provide detailed information about farm characteristics and management aspects regarding DCC and milking given by the farmers at the time of the telephone interviews. Table 5 shows the personal views of the 17 farmers on milkability problems on their own farms. Supplemental Files S2 and S3 (see Notes) show further perceptions of the farmers regarding their own DCC systems and additional information on weaning and

Table 3. Farm and general management characteristics of the 17 interviewed dam–calf contact (DCC) farms; farms 1 to 10 were visited for on-farm data collection

ID	No. of cows	Breeds[1]	Production system	Housing cows[2]	Housing calves[3]	Organization of calvings	Parturition management
1	26	SFL, HO	Conventional	F	CC	Continuous	Calving pen
2	18	SFL	Conventional	F	CC	Continuous	Calving pen
3	38	SFL, SM, HO	Conventional	F	Cow barn (permanently)	Continuous	Calving pen
4	20	BS, HO SFL	Organic	F	CC	Continuous	Calving in the herd
5	38	SFL	Organic	F	CPN (visual; direct)	Continuous	Calving pen
6	22	RFL	Organic	F	CPN	Continuous	Calving pen
7	18	SM, BV	Organic	T	CPN (visual)	Seasonal	Calving pen
8	12	BV	Organic	T	CPN	Seasonal	Calving pen
9	18	SFL, HO, JE	Organic	F	CPN (visual; direct)	Continuous	Calving pen
10	20	HO, KC, SFL	Organic	F	CPN	Seasonal	Calving pen
11	16	BV, GRV, JE	Organic	F	CC	Continuous	Calving pen
12	14	HO, AN	Conventional	F	cow barn (permanently)	Continuous	Calving pen
13	5	JE	Organic	F	CC	Seasonal	Calving pen
14	11	HIN, GRV, JE	Organic	F	CPN (visual)	Seasonal	Calving pen
15	25	BV	Organic	F	CC (open during daytime)	Continuous	Calving pen
16	9	BV, RFL	Organic	F	CC	Continuous	Calving pen or pasture
17	65	BV, HO, SM	Conventional	F	CPN (visual contact)	Continuous	Calving pen

[1]Breeds: SFL = Swiss Fleckvieh; HO = Holstein; SM = Simmental; BS = Brown Swiss; RFL = Red Fleckvieh; BV = Braunvieh; JE = Jersey; KC = Kiwicross; GRV = Grauvieh; AN = Angus; HIN = Hinterwälder.

[2]Housing cows: F = freestall housing; T = tiestall housing.

[3]Housing calves: CC = calf creep (calves can freely return to the cow barn from the creep); CPN = calf pen (closed pen for calves) with no contact, visual contact, direct contact, or visual and direct contact to the cow barn.

Table 4. Aspects of management and milking related to dam–calf contact (DCC) in the 17 interviewed DCC farms

ID	Type of DCC[1]	Timing of suckling and milking	Weaning age and mode[2] (fr)	Weaning age and mode[2] (m and fnr)	Cow milked throughout lactation	Milking frequency[3]	Milking system[3]
1	WDC	24-h contact	5–6 mo (gw)	4–5 mo (aw 1 wk before slaughter)	Yes	2×	Parlor
2	WDC	24-h contact	7–8 mo (gw)	12 mo (aw; slaughter)	No milking from calf age of 2–3 mo until separation	2×	Parlor
3	WDC	24-h contact	3 wk (aw; sale for fattening)	3 wk (aw; sale for fattening)	Yes	2×	Parlor
4	WDC	24-h contact	5–6 mo (gw)	4–5 mo (aw; slaughter)	Yes	2×	Pipeline
5	STC	2× 1–2 h before milking	3–5 mo (gw)	3–4 wk (aw at sale to fattening unit)	No milking from calf age of 2–3 mo until separation	2×	Parlor
6	STC	2× 45 min before milking	6 mo (gw)	6 mo (aw; slaughter)	First-lactating cows used as suckler cows	2×	Pipeline
7	STC	2× 15 min before	5 mo (gw)	6 mo (aw; slaughter)	No milking from calf age of 2–3 mo until separation	2×	Pipeline
8	STC[4]	2× 45 min after milking	3–5 mo (gw)	3–5 mo (aw; slaughter)	Yes	2×	Pipeline
9	STC[4]	2× maximum 4 h after milking	5 mo (gw)	7 mo (gw)	Yes	2×	Pipeline
10	STC[4]	2× maximum 1 h after milking	5–6 mo (gw)	5–6 mo (gw)	Yes	2×	Parlor
11	WDC	24-h contact	2–12 mo (gw)	2–12 mo (gw)	Yes	1×	Bucket
12	WDC	24-h contact	3 mo (gw)	4–5 mo (aw; slaughter)	Dams of older male calves milked 1×/d	2×	Bucket
13	WDC	24-h contact	8–9 mo (gw)	6–8 mo (aw; slaughter)	Yes	1×	Bucket
14	PC	Daytime	8–9 mo (gw)	8–9 mo (m: aw; slaughter); 6 mo (fnr: aw; slaughter)	Yes	1×	Bucket
15	PC	Daytime	5 mo (gw)	4–5 mo (aw; slaughter)	No milking from calf age of 2–3 mo until separation	1×	Parlor
16	WDC	24-h contact	6 mo (gw 1 wk before slaughter)	7 mo (gw 1 wk before slaughter)	Yes	1×	Parlor
17	STC	3× 15 min	2–3 mo (aw from STC)	2–3 mo (aw from STC)	Yes	AMS	AMS

[1]Type of DCC: WDC = whole-day contact; STC = short-time contact before or after milking; PC = part-time contact (daytime or nighttime);

[2]Weaning: fr = female calves used for dairy cow replacement; fnr = female calves not used for dairy cow replacement; m = male calves; gw = gradual weaning (daily contact time of cow and calf is reduced gradually over some days or weeks); aw = abrupt weaning.

[3]AMS = automatic milking machine.

[4]Gradual reduction from WDC to STC between the second week and the third month of life.

milking given by the farmers in the interviews (Supplemental File S1, see Notes).

Milkability on DCC Farms

The first part of the statistical analysis aimed to test whether non-nursing cows (including cows from reference farms) were comparable across systems. Farm type (no contact, WDC, CBM, CAM) was not related to any of the outcome variables (fat content: $P = 0.13$; machine milk yield: $P = 0.80$; decline phase: $P = 0.15$; bimodality: $P = 0.12$; hind leg activity: $P = 0.20$; swellings at the teat base: $P = 0.27$).

Clear Ejection Disorders. Of the 701 observations of the DCC and no-contact farms, clear ejection disorders were detected in 20 observations. Two of these observations were registered in one nursing cow on a CBM farm when the calf suckled 1 h before milking. One observation with a clear ejection disorder was recorded in one non-nursing cow on a CAM farm. Seventeen observations with clear ejection disorders were recorded on WDC farms: 13 clear ejection disorders had been observed on WDC farms in 11 nursing cows that were suckled in the last 5 h before milking, whereas 4 of the observations were recorded on WDC farms in 2 non-nursing cows. No observation of a clear ejection disorder occurred on a reference farm. Due to the low occurrence of ejection disorders relative to the total number of observations, no statistical analyses were performed.

Fat Content of the Stripping Milk. The fat content of the stripping milk was lower in the nursing cows compared with the non-nursing cows ($P = 0.007$), irrespective of the DCC type (Figure 1). The stripping milk fat content of the non-nursing cows was 8.7 [7.8, 9.7] g/100 g (estimated mean [lower, upper 95% CI]) and 7.1 [6.1, 8.2] g/100 g for the nursing cows.

Machine Milk Yield. The machine milk yield of the nursing and non-nursing cows was comparable on CAM farms (non-nursing: 8.7 kg, nursing: 8.5 kg). The machine milk yield of the nursing cows was lower than that of the non-nursing cows on WDC farms (non-nursing: 9.3 kg, nursing: 5.2 kg) or on CBM farms (non-nursing: 9.3 kg, nursing: 5.2 kg; $P = 0.002$, Figure 2). Machine milk yield was lower at higher average mouthpiece chamber vacuum levels during the main milking phase ($P < 0.001$). A machine milk yield of 8.2 kg [7.2, 9.1] was recorded with an average vacuum of 10 kPa, whereas a machine milk yield of 6.6 kg [5.4, 7.8] was recorded with an average vacuum of 40 kPa.

Decline Phase. In the nursing cows, the duration of the descent phase tended to be shorter compared with the non-nursing cows ($P = 0.076$). The descent phase lasted 2.20 min [1.51, 2.88] for the nursing cows compared with 2.71 min [2.04, 3.38] for the non-nursing cows.

Table 5. Perception of milkability problems on the own dam–calf contact (DCC) farm

ID	Milkability problems	Disturbance of the milking routine	Percentage of cows affected	Recurrent milkability problems in the same animals[1]	Perceived influence of lactation stage[1]	Measures taken to improve milkability[2]	Change of milk fat contents since adopting DCC
1	Yes	Medium	30	Yes	More problems in early lactation	OT	Unclear
2	Yes	Low	80	NA	More problems when calf is absent and leaves the farm	C	No milk recording
3	Rarely	Low	<10	Yes	More problems after separation	No	No
4	Yes	Medium	50	Yes	More problems in early lactation	C, BF, H	Lower
5	Yes	Low	<10	Yes	No	No	Higher
6	Rarely	Low	<10	NA	More problems in early lactation	C	Unclear
7	Rarely	Low	<10	No	No	C	No
8	Yes	High	50	Yes	No	C, OT, BF, H	Lower
9	Yes	Medium	20	Yes	More problems after 2–3 lactation months	C, BF, H	Lower
10	Yes	High	10	Yes	More problems in early lactation	C, OT	Lower
11	Yes	Low	20	No	More problems in early lactation	No	Lower
12	Yes	Low	10	Yes	No	No	No
13	Yes	Low	20	Yes	More problems in early lactation	C	Unclear
14	Yes	Low	10	No	More problems in early lactation	No	Unclear
15	Yes	Low	10	Yes	More problems in early lactation	OT, H	Lower
16	Rarely	Low	<10	NA	More problems with older calves	OT	No milk recording
17	Rarely	Low	<10	NA	NA	No	No milk recording

[1]NA = not applicable.
[2]Measures taken to improve milkability: OT = injecting oxytocin; C = bringing the calf to the milking parlor; BF = blow fix (blowing air into the vagina); H = homeopathy.

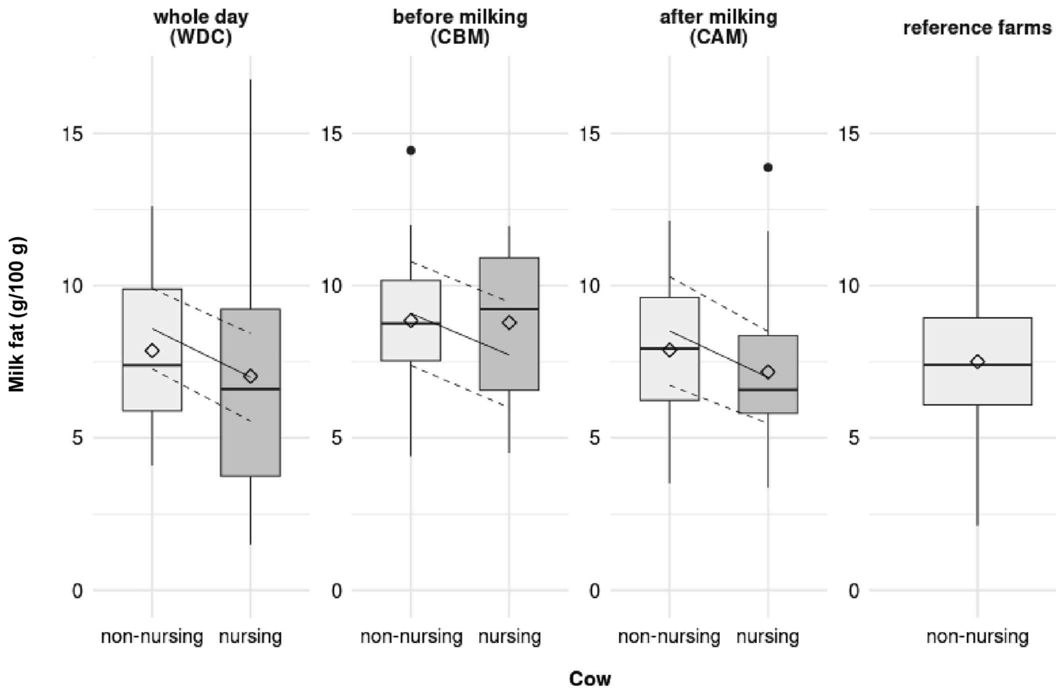

Figure 1. Milk fat content in the stripping milk (g/100 g) for nursing and non-nursing cows in whole-day contact (WDC), contact before milking (CBM), and contact after milking (CAM) systems ($P = 0.007$). Reference farms (no contact) are shown as reference and were not included in the model. Boxplots show medians and interquartile and absolute ranges of raw data plus outliers. Solid lines show the estimated means, dashed lines the estimated lower and upper 95% CI. Diamonds indicate group means.

Bimodality of the Milk Flow Curve. The occurrence of bimodal milk flow curves is shown in Table 6. No statistically significant differences were confirmed.

Hind Leg Activity. Irrespective of the type of DCC or nursing versus non-nursing, cows showed 0.73 to 1.66 hind leg activity phases per minute of milking.

Teat Bonitation. The occurrence of swellings at the teat base relative to the DCC type is represented in Table 7. No statistically significant differences were confirmed.

DISCUSSION

In this study, we identified the status quo of Swiss DCC farming in regard to management and milking by means of phone interviews and evaluated the effects of DCC on milking, behavior in the milking parlor, and teat condition by means of an on-farm data collection. Our findings revealed a high variation in cow–calf management and farm structures. The on-farm data collection demonstrated the least negative effect on machine milk yield in the CAM group. The fat content of the stripping milk was reduced in the nursing cows regardless of the type of DCC. We found no differences (nursing vs. non-nursing and between DCC types) with regard to various milkability parameters, hind leg activity during milking, and teat condition.

Farm Selection and Study Limitations

The context of Swiss DCC farming predefines a very small population size, and farm structures are diverse. There is no common approach to DCC farming. Farmers who start DCC farming mainly develop their systems as deemed fit for their personal and farm-related circumstances. Our sample for the farmer interviews gives a realistic picture of the current Swiss DCC farming practices, because these were farmers who contacted the Centre for Dam–Calf Contact Rearing during the last 2 years. Due to the inclusion requirements for the database of the Centre for Dam–Calf Contact Rearing, most of the farms did not separate cows and calves before the age of 3 mo. However, in Europe, DCC rearing with contact durations of more than 90 d is more frequent than shorter contact durations, and the average suckling period of Swiss CCC farms is around 5 mo (Eriksson et al., 2022). The longer the period of “milking and nursing” is, the more affecting are milkability problems. Our selection, therefore, helped us address the relevant farms with the interview questions on milkability.

Despite the low population size and high diversity of management approaches, we were able to identify 3 DCC types with a clearly different timing of suckling and milking for comparison of the effect on milkability in the

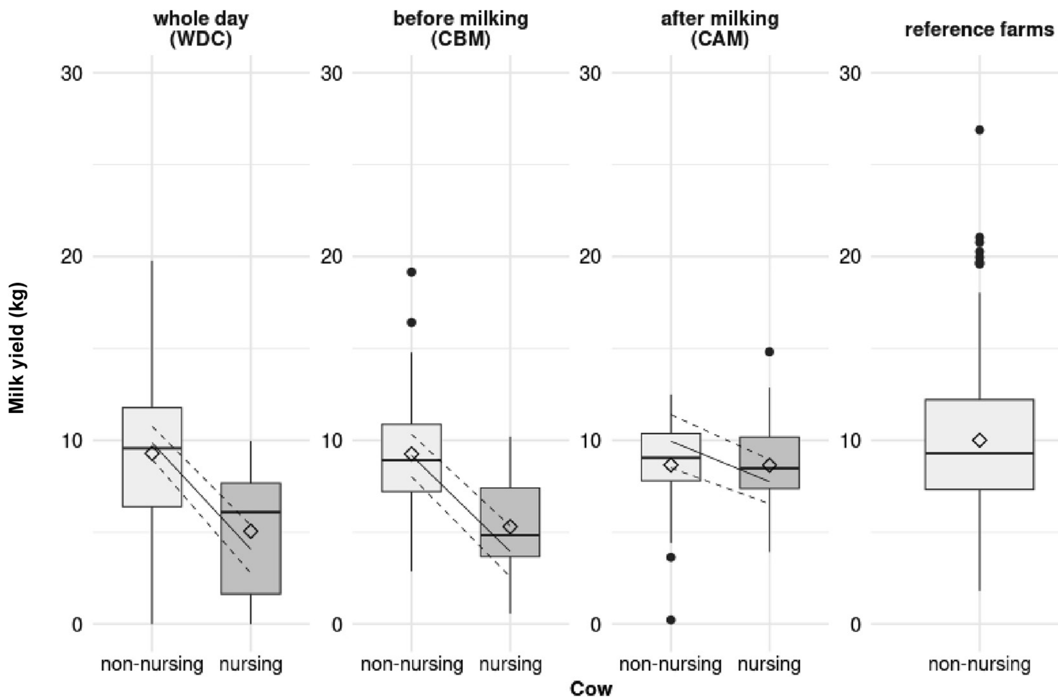

Figure 2. Machine milk yield per milking in kilograms for nursing and non-nursing cows in whole-day contact (WDC), contact before milking (CBM), and contact after milking (CAM) systems ($P = 0.002$). Reference farms (no contact) are shown as reference and were not included in the model. Boxplots show medians and interquartile and absolute ranges of raw data plus outliers. Solid lines show the estimated means, dashed lines the estimated lower and upper 95% CI. Diamonds indicate group means.

subsequent on-farm data collection. The current situation of DCC farming in Switzerland allowed us to include 3 CAM, 3 CBM, and 4 WDC farms in our on-farm data collection. Due to the low sample size at the farm level, main effects of farm type must be interpreted with caution when generalizing our results. Using non-nursing cows of the DCC farms as internal controls eliminated confounding factors related to individual farm management to some degree, although this approach resulted in a high difference in DIM between non-nursing cows (194.3 d) and nursing cows (54.2 d). Given the known relationship between milk yield, milk flow, duration of prestimulation, and the occurrence of bimodality with DIM and lactation number (Sandrucci et al., 2007), DIM and lactation number were included as covariates in the statistical model. Although these covariates may help explain some variation within groups, lower DIM for nursing cows are self-evident in DCC farming where calves are weaned after a certain duration of nursing (2–12 mo in our study). Accordingly, the DIM of reference farms

Table 6. Proportion and absolute number of observations (n_{bimo}) of bimodal milk flow curves for nursing and non-nursing cows on farms with different dam–calf contact (DCC) types (total observations [n_{tot}] = 704)[1]

	Proportion and absolute number of observations/cows with bimodal milk flow curves			
Group	Whole-day (WDC)	Before milking (CBM)	After milking (CAM)	Reference farms
Non-nursing cows (%)	13 $n_{tot} = 121$ $n_{bimo} = 16$ $n_{cow} = 10$	6 $n_{tot} = 64$ $n_{bimo} = 4$ $n_{cow} = 4$	44 $n_{tot} = 32$ $n_{bimo} = 14$ $n_{cow} = 9$	27 $n_{tot} = 343$ $n_{bimo} = 93$ $n_{cow} = 52$
Nursing cows (%)	12 $n_{tot} = 58$ $n_{bimo} = 7$ $n_{cow} = 6$	17 $n_{tot} = 36$ $n_{bimo} = 6$ $n_{cow} = 6$	28 $n_{tot} = 50$ $n_{bimo} = 14$ $n_{cow} = 9$	—

[1]n_{cow} indicates the number of animals with bimodal milk flow curves during at least one of the 2 milkings observed per animal. Data for reference farms (no contact) are shown as reference.

Table 7. Proportion and absolute number of cows (n_{teat}) with swellings at the teat base for nursing and non-nursing cows on farms with different dam–calf contact (DCC) types (n_{total} = 357)[1]

	Proportion and absolute number of observations or cows with swellings at the teat base			
Group	Whole-day (WDC)	Before milking (CBM)	After milking (CAM)	Reference farms
Non-nursing cows (%)	25 n_{tot} = 16 n_{teat} = 4	15 n_{tot} = 20 n_{teat} = 3	20 n_{tot} = 61 n_{teat} = 12	36 n_{tot} = 177 n_{teat} = 63
Nursing cows (%)	11.5 n_{tot} = 26 n_{teat} = 3	14.3 n_{tot} = 28 n_{teat} = 4	13.8 n_{tot} = 29 n_{teat} = 4	—

[1]Data for reference farms (no contact) are shown as reference.

were comparable to that of non-nursing cows on DCC farms. The large difference in DIM between nursing and non-nursing cows may have led to an underestimation of the reduction in milk yield due to poor milkability or suckling, because milk yield decreases in the course of lactation. This applies equally for the stripping milk fat levels: Milk fat contents increase in the course of lactation, which may have led to an underestimation of the reduction in fat levels in nursing cows. Further, it was not possible to include nursing first-parity cows on all of the farms as some farmers did not milk first-parity cows at all. Future research should focus on balanced animal numbers, lactation numbers, and DIM to disentangle the effects of nursing versus non-nursing cows and lactation stages.

Interviews: Farming Practice and Milkability in DCC Rearing in Switzerland

Status Quo of DCC Rearing in Switzerland. The interview part of our study revealed high variability in individual approaches regarding all inquired aspects of DCC management and milking. Due to the diverse character of Swiss agriculture, for example, regarding cattle management (Lava et al., 2016) or milking systems (Heitkämper, et al., 2021), farmers face a broad range of structural preconditions when starting a DCC system. Adaptation to individual preconditions entails tailored management decisions, leading to a diverse overall picture. In a recent qualitative interview study, the spectrum of approaches to DCC management reported by the 12 participating farmers was similarly broad (Johanssen et al., 2023). A Danish study investigating farmers' motivations and considerations regarding different types of CCC systems revealed that most of the influencing factors, such as practical considerations, ethical responsibility, and the farm's image toward the public and the farming community, have a very personal character (Bertelsen and Vaarst, 2023), which may further diversify the landscape of DCC systems.

In our sample, the average herd size was 22 cows, which corresponds to the Swiss average (23 cows; Federal Office for Statistics, 2023). In Eriksson et al. (2022), the average herd size of Swiss CCC farms was 30 cows. Internationally, DCC systems are implemented on large specialized farms (Vaarst and Christiansen, 2023) as well as on traditional smallholdings (Eriksson et al., 2022).

Our sample included one farm that abruptly separated cows and calves 3 wk after birth. Removing calves from their dams at only some weeks of age is suboptimal regarding the development of the calves' immune system and, therefore, calf health (Hassig et al., 2007; Lopez et al., 2020). Dam–calf contact over several months is more suited to fulfill the intrinsic needs of cows and calves, as under natural conditions, the suckling period lasts for 7 to 14 mo (Reinhardt and Reinhardt, 1981), and weaning is a gradual process (von Keyserlingk and Weary, 2007). However, removing calves from their dams after a few days or weeks is not an exception in CCC farming practice (Eriksson et al., 2022).

Interpretation of "Poor Milkability." When estimating milkability problems, farmers in our study generally used the terms "she doesn't give the milk well," "she doesn't let the milk down," or "she keeps the milk for the calf." This indicates that farmers suspected a malfunction of the milk ejection reflex in response to machine-milking in their nursing cows. In fact, during a normal milking routine, it is not possible to detect whether problematic milk removal is due to impaired milk let-down or other factors inhibiting the milk flow through the teats, for example, anatomical dysfunctions (Querengässer et al., 2002) or unsuitable milking machine settings. The high discrepancy between the farmers' estimates and the measured cases of clear ejection disorders in our study indicates that a considerable share of milkability problems were caused by factors other than reduced or absent OT release. This overestimation is in accordance with a Swiss study among farmers operating a no-contact rearing system, in which 31% of cows suspected of being affected by milk ejection disorders by the farmers suffered from anatomical disorders of the udder or had no disorder. Further, a high response rate of 75% of questionnaires showed that poor milkability as an issue of interest is not limited to nursing dams (Belo et al., 2009). However, in their study, Belo et al. (2009) detected actual milk ejection disorders by measuring residual milk after OT treatment, which is more accurate than our definition of clear ejection disorders (Belo et al., 2009).

To clarify the wordings used by farmers and scientists to describe milkability problems, a reflection of the term "poor milkability" appears essential. The term "poor milkability" is used when of physiological or anatomical dysfunctions of the udder impede complete evacuation at milking (Belo et al., 2009). A "milk ejection disorder" presents if OT release in response to teat stimulation is absent or insufficient to evoke milk ejection. An "incomplete milk let-down" refers to a situation in which the milk ejection reflex was activated but not maintained over a threshold level during the total milking duration. An "incomplete milk removal" describes poor milkability if the milking machine does not remove the whole milking (except from the residual milk) from the udder. Both milk ejection disorders and incomplete milk let-down impede complete milking of the alveolar fraction and are physiologically induced. In case of incomplete milk removal, anatomical disorders or inappropriate milking machine settings cause milk to remain in the cistern after successful milk ejection.

On-Farm Data Collection: Results and Parameters Used

To obtain a detailed picture of milking functionality and performance, we combined parameters indicating a dysfunction of milk let-down (clear ejection disorders) and incomplete udder emptying (fat level of stripping milk) with classical milkability parameters indicating the efficiency of milking (e.g., machine milk yield and milk flow). Aspects of the milking technique (duration of prestimulation and vacuum level of the mouthpiece chamber) were included as adjustment factors to account for farm– and cow–individual differences in milking practices.

Clear Ejection Disorders. In a total of 701 milkings, 20 met the criteria for clear ejection disorder. Seventeen of these observations occurred on WDC farms and zero on reference farms. In terms of methodology, the previously supposed overestimation of milkability problems by farmers must be put in the context of our chosen definition of a "clear ejection disorder," which, to our knowledge, has not been used before. On the one hand, based on the wording of the farmers, their estimates might have referred to "poor milkability" rather than "milk ejection disorders." On the other hand, for CAM cows, our definition (<1 kg milk and no suckling during >1 h before milking) may have been too narrow to identify a milk ejection disorder. In these cows, udders were full at milking, and even if only the cisternal fraction was harvested, machine milk yields over 1 kg could still be found in cows with a milk ejection disorder. However, with the exception of one cow, CAM cows did not have machine milk yields of less than 3 kg. Cisternal milk of 3 kg would imply a machine milk yield of 15 kg (20% of 15 kg), which was not reached in any of the CAM cows. Further, Jenni et al. (2024) could not detect any amount of cisternal milk greater than 3 kg in cows with the same machine milk yields in their experiment. This implies that despite our narrow definition, we did not underestimate milk ejection disorders in CAM cows; rather, the rate of milk ejection disorders was low for this type of DCC.

To determine the cisternal fraction as a threshold level for a milk ejection disorder and, thus, to further investigate the occurrence of milk ejection disorders and incomplete milk let-down for different types of DCC, the average machine milk yields and the udder filling before milking should be considered at the individual level. More accurate parameters for identifying milk ejection disorders would be plasma OT levels (Tančin et al., 2001b) or removing residual milk by OT injection. However, these approaches require venipuncture, permanent jugular cannulas, or both, which is a highly extensive method if applied in a large sample or in multicenter studies. It is, therefore, difficult to assess the actual prevalence of milk ejection disorders in a large population that could serve as a reference for our results. Bruckmaier et al. (1992) suggest that 1% of primiparous cows in Switzerland are affected by disturbed milk ejection (Bruckmaier et al., 1992), whereas Kraetzl et al. (2001) indicate that 10% of parturient primiparous cows are affected. Both authors exclusively refer to non-nursing cows.

Fat Content of the Stripping Milk. In the present study, the fat content of stripping milk was reduced in the nursing cows compared with the non-nursing cows regardless of the type of DCC. In previous studies, a reduced fat content of the whole milking was demonstrated and used as an indicator or evidence of disturbed alveolar milk ejection in nursing cows (Zipp et al., 2018; Barth, 2020). The calves' access to the udder and the individual suckling activity of each calf determine the udder filling at the start of milking. Milkings of partially emptied udders, for example, in a CBM system, will generally contain more fat than milkings of CAM cows as a part of the low-fat milk fraction is already removed by calf suckling before milking starts. Fat levels of sampled whole milkings can therefore neither be compared among different DCC types nor with the milkings of non-nursing cows, as they can differ even if the degree of udder evacuation after milking is the same.

In contrast to whole milkings, the stripping milk represents the last milked fraction of a milking. As the milk fat content increases steadily during the process of milking, the stripping milk generally contains more fat than the whole milking. If udders are not completely milked, stripping milk samples will contain less fat than completely milked udders. This can be either because the fat-rich last fraction of alveolar milk is still stored in the alveoli when the sample is drawn or, in cases of technical or anatomical problems, because the fat-rich last fraction of alveolar milk is diluted by the remaining milk in the cisterns. This snapshot of the fat content in the last milk removed might have some advantages over whole milking samples. However, the fat content of the stripping milk as a parameter to predict udder emptying was only reliable if udders were emptied at >60% (Jenni et al., 2024).

In our study, the reduction in stripping milk fat content in nursing cows was independent of the type of DCC, meaning that after milking, more milk remained in the udders of nursing cows compared with non-nursing cows. This corresponds to the interpretation of the findings in which whole milkings were sampled (Zipp et al., 2018; Barth, 2020). In summary, one possible explanation for poor milkability in nursing cows is that udder quarters are emptied to different extents. Another interesting speculation proposed by some authors (Boden and Leaver, 1994; Bar-Peled et al., 1995) is that some nursing cows keep the milk in the udder at milking as a physiological response to ensure calf supply, a notion commonly shared by many of the interviewed farmers. Furthermore, bringing the calf to the milking parlor was the most frequently used measure and was described as a very effective tool to trigger milk release in cows with poor milkability. It remains unclear whether nursing in general, that is, the maternal bond between cow and calf, affects milking via neuroendocrine pathways or higher brain centers (or both), or whether cow–individual factors can affect milk let-down. In future studies, using different contact systems in subsequent lactations in the same cows, in combination with OT measurements, could provide detailed information about the relationship between contact types and milk ejection disorders.

Prestimulation, Mouthpiece Chamber Vacuum, and Hind Leg Activity. In this study, no differences regarding the duration of prestimulation were found between nursing and non-nursing cows or between DCC types.

In another study, an extended time of manual prestimulation did not result in higher fat values or machine milk yield, that is, better udder evacuation in nursing cows having whole-day contact with their calves (Zipp et al., 2018). Prestimulation time must be sufficient to evoke full milk ejection. As a low udder filling before milking leads to an increased time of prestimulation needed for OT release (Bruckmaier et al., 1994; Bruckmaier and Hilger, 2001), the applied prestimulation time may not have been sufficient for cows with CBM and possibly for cows with WDC. However, low rates of bimodal milk flow curves in those cows indicate that prestimulation time was sufficient, despite partially emptied udders (Sandrucci et al., 2007; Ambord and Bruckmaier, 2009).

Regarding mouthpiece chamber vacuum levels, we expected higher overmilking times related to higher vacuum levels due to partially emptied udders in nursing WDC and CBM cows to cause more cases of teat deterioration and hind leg activity phases. High mouthpiece chamber vacuum levels showed the predicted effect on the teats (with a tendency for more deteriorated teats with a higher mouthpiece chamber vacuum), but this was regardless of the type of DCC and from nursing versus non-nursing. This emphasizes the importance of appropriate vacuum levels to conserve healthy teats and indicates that the nursing cows did not experience more pain or discomfort at milking compared with the non-nursing cows, which is supported by our hind leg activity data: a higher mouthpiece chamber vacuum did not cause more hind leg activity phases. This finding is consistent with other studies that used similar parameters (Schneider et al., 2007; Zipp et al., 2018) and stepping behavior (Zipp et al., 2014) during milking. Nevertheless, these studies found other indications of stress or discomfort, such as a higher number of vocalizations, tense postures, wide-open eyes, and absence of rumination (Schneider et al., 2007), as well as more elimination behavior (Zipp et al., 2014), which were not investigated in this experiment. More hind leg kicking activity has been shown to occur with a higher average mouthpiece chamber vacuum (Meyer et al., 2021). Measuring acceleration at the milking cluster as a proxy for hind leg activity does not allow for differentiating whether a cow is stepping or kicking. Distinguishing between tripping and kicking could be important in determining the cause of increased hind leg activity. In addition to the possibility that a higher average mouthpiece chamber vacuum could lead to more kicks, different types of milking clusters and pulsation should also be considered to allow a more accurate determination of the causes of higher hind leg activity.

Effects of the Type of DCC on Machine Milk Yield. In nursing CAM cows, machine milk yield was higher than in nursing WDC and CBM cows. This could be due to the higher udder filling at the start of milking, which facilitates milk ejection (Bruckmaier and Hilger, 2001). Within CAM farms, the machine milk yield was nearly the same in the nursing and non-nursing cows. One possible cause may be that nursing CAM cows produced more milk (machine milk yield plus suckled milk) compared with non-nursing CAM cows. A higher total milk production during the suckling period was previously found at frequent milking (Bar-Peled et al., 1995) or in Zebu-crosses (Negrão and Marnet, 2002). However, in most studies where calves suckled after milking, the amount of machine milk yield was reported to be reduced (de Passillé et al., 2008; Mendoza et al., 2010), just as in the WDC and CBM cows in this study. Barth (2020) found that machine milk yield was reduced in whole-day and short-time (before milking) DCC systems, but not in a nighttime contact system in which calves had contact with their dams after evening until morning milking. Another possibility is that the higher machine milk yield in the nursing CAM group leads to an insufficient milk supply for calves suckling after milking. Proper and sufficient daily contact-times are therefore important in CAM (as well as in CBM) systems to ensure adequate calf supply. Another option for DCC systems with short daily contact periods after milking might be to remove the milking cluster early, thereby leaving a certain amount of milk in the udder for calf consumption. Overall, in all DCC systems, suckled milk and adequate calf supply should be considered in addition to machine milk yield when drawing conclusions about the productivity of nursing cows.

CONCLUSIONS

In this study, improved machine milk yield and milk flow were found for nursing cows in a CAM system compared with WDC and CBM. However, various other milkability parameters, teat condition, and hind leg activity did not differ among DCC types and nursing versus non-nursing cows. For better interpretation of the stripping milk fat content and clear ejection disorder as determinants of a dysfunction of the milk ejection reflex, the level of udder filling before milking, which is likely to differ between DCC types, should be taken into consideration. The large variation between the farms concerning the management details of the DCC types, such as calf location, housing systems, or cow breeds, implies caution when generalizing the results. Further research in a controlled environment and with adapted milking machine settings would be useful, whereas the potential for implications in practical farming should be kept in mind.

NOTES

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Nonstandard abbreviations used: AMS = automatic milking machine; AN = Angus; aw = abrupt weaning; BF = blow fix; BS = Brown Swiss; BV = Braunvieh; C = bringing the calf to the milking parlor; CAM = contact after milking; CBM = contact before milking; CC = calf creep; CCC = cow–calf contact; CPN = calf pen; DCC = dam–calf contact; F = freestall housing; fnr = female calves not used for dairy cow replacement; FSVO = Food Safety and Veterinary Office; fr = female calves used for dairy cow replacement; GLMER = generalized linear mixed-effects model; GRV = Grauvieh; gw = gradual weaning; H = homeopathy; HIN = Hinterwälder; HO = Holstein; JE = Jersey; KC = Kiwicross; LMER = linear mixed-effects model; m = male calves; NA = not applicable; n_{bimo} = absolute number of observations; n_{tot} = total observations; OT = oxytocin; PC = part-time contact; RFL = Red Fleckvieh; SFL = Swiss Fleckvieh; SM = Simmental; STC = short-time contact; T = tiestall housing; WDC = whole-day contact.

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