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Abstract

Calves in most dairy farms are separated from their dams either immediately or within a few hours after birth, prompting increasing concern of the society for reasons of animal welfare. The aim of this study was to identify systems to maintain cow-calf contact (**CCC**) that balance the benefits for calf growth and health against the negative impacts on sellable milk and stress at weaning. We tested reuniting cows and calves for 20 min before (**Before**-group) or 2.5 h after (**After-**group) morning milking (in Trial 1) or for a 9 h period between the morning and evening milkings (**Half-day**-group, in Trial 2). In **Control**-groups, calves were separated from their dam at birth and fed with artificial nipple with tank milk provided daily at 13% (Trial 1) and 14% (Trial 2) of their BW. In both trials, each practice was applied on a group of 14 dam–calf pairs (7 Holstein [**Ho**] and 7 Montbéliarde [**Mo**]). All calves were weaned at a BW of at least 100 kg. In Trial 1, the After-group was prematurely stopped when the

calves were 8 weeks of age as calf growth became limited (340 g/d) due to low milk intakes (2.97 kg/d). During the first 8 weeks of lactation, milk yield at the parlour was 29%, 51% and 42% lower in After-, Before- and Half-day-cows respectively compared to Controls. From Week 14 to 16 when all calves were separated from their dam, Before-cows still produced 25% less milk than Control-cows while Half-day-cows reached the milk yield of Control-cows within a week. There were no significant differences in milk somatic cell count and in frequency of health disorders (cows and calves) between suckling and Control- groups. Compared to Control-calves, calf growth until weaning was higher in the suckling calves in Trial 1 (861 vs. 699 g/d) and similar in Trial 2 (943 vs. 929 g/d). At weaning, Before- and Half-day-calves started to vocalize earlier and continued to vocalize longer than Controls. In conclusion, the best compromise between cow milk yield and calf growth is a long period of CCC (9 h) between the morning and evening milkings. Still abrupt weaning stresses both cows and calves even if CCC has been restricted before separation.

Keywords: cow-calf contact, milk feeding, milk yield, growth, weaning

Implications

Consumers are increasingly questioning the practice of separating calves from their dams at birth. Compared to short periods of suckling immediately before or after milking, a half-day contact during the day between milkings provides a good compromise between sellable milk and calf growth. This practice could conciliate consumers and farmers views. Solutions should be explored to reduce calves and cows stress due to abrupt weaning.

Introduction

Calves in most dairy farms are separated from their dams either immediately or within a few hours after birth (Busch et al., 2017). They are fed milk replacers or non-marketable milk, distributed by an automatic milk feeder or in buckets, and receive increasing amounts of solid feed until weaning (Le Cozler et al., 2012). Female calves, which are the future replacement heifers, are generally weaned off from milk at 8–10 weeks of life, or 12 weeks of age or more in case of organic farming. Male calves are generally sold at a few weeks of age to be fattened in specialized farms. Dairy calves therefore very rarely suckle their dam (Pardon et al., 2012). Early separation between cows and calves enables farmers to get the most milk from the cows and control the amount of colostrum and milk ingested by the calves. This practice however creates animal welfare issues for consumers (Placzek et al., 2021) who associate the welfare of an animal with possibilities to express its natural behaviours (Lund et al., 2006). In dairy farming, this includes calves suckling their dam. Some farmers already let calves suckle their dam or other cows at least for short periods after birth, either to promote calf health or to reduce workload and/or production costs (Michaud et al., 2018).

Several experiments were carried out to assess how cow-calf contact (**CCC**) affects milk production and composition. Considering the total milk produced by cows (either milked or taken by the calves), a combination of milking and suckling can make cows produce more milk due to teat stimulation by the calves and better udder emptying (Sandoval-Castro et al., 2000). This increase in total milk production — and even sellable milk output — was reported in dual purpose breeds, such as Salers or Brahman x Holstein cows, in which calf stimulation before milking is necessary to activate milk ejection (Cozma et al., 2013; Cozma et al., 2016; Tesorero et al., 2001).

71 However, in dairy cows selected for high milk production, total milk production is
72 sometimes reported to be unaffected by nursing (Mendoza et al, 2010) in particular
73 when sucking occurs just before and after milking (Cozma et al., 2013). Most of the
74 time, whole-day cow-calf contact is found to significantly reduce the milk yield by 10
75 to 12 kg/d (Pomiès et al., 2010; Zipp et al., 2018). Krohn (2001) suggested that
76 reducing the duration of CCC could limit the suppressive effects of suckling on milk
77 ejection.

78 Suckling may also affect milk fat content, because milk fat content changes over the
79 course of milking (Rico et al. 2014) and the proportion of the milk produced by the
80 cow that is collected during milking varies with suckling. Consequences of suckling
81 on milk protein content are not clear so far (Johnsen et al., 2016). Boden and Leaver
82 (1994) and Barth (2020) found an increase of milk protein content in suckled cows
83 while Cozma et al. (2013) found a decrease, and Froberg et al. (2007) and Sandoval-
84 Casto et al. (1999) found no differences.

85 Calves reared with their dam can grow faster compared to artificially-reared calves, in
86 particular when the latter are fed a restricted milk diet (Flower & Weary, 2001). The
87 faster growth may be due to higher milk consumption as well as to stimulation of
88 anabolism by the higher release of oxytocin in suckling calves than bucket-fed calves
89 (discussed by Uvnäs-Moberg et al., 2001). Therefore, suckling may have positive
90 effects on calves' growth that are not solely related to the higher ingestion of milk.

91 A common belief is that separating the calf at birth limits the risk of transmission of
92 diseases and is better for both calf and cow health. Beaver et al. (2019) reviewed the
93 available literature and found no evidence that suckling has negative effects on
94 health. For instance, when latency to first suckling and quality of colostrum are
95 controlled, leaving the calf with its dam at birth has no effect on risk for diarrhoea or

on mortality (Meagher et al., 2019). In addition, suckling can benefit cows by reducing the incidence of mastitis while others could not find an effect (reviewed by Johnsen et al., 2016). Pomiès et al. (2010) and Cozma et al. (2013) reported lower milk somatic cell count (**SCC**) in nursing cows.

Under natural conditions, weaning occurs gradually at 8–10 months of age (Reinhardt & Reinhardt, 1981) , and the cow–calf bond persists after weaning (Veissier et al., 1990). In dairy farming promoting CCC over long duration, weaning is provoked by an abrupt separation of dam and calf that causes stress to both cows and calves (Flower & Weary, 2001; Hudson & Mullord, 1977; Lidfors, 1996; Weary & Chua, 2000). Cow–calf bonding is viewed as positive for animal welfare, but the stress induced by the separation is a welfare problem (Weary et al., 2008). Habituating calves to be separated from their dam has been shown to reduce stress at weaning in beef calves (Price et al., 2003).

Restricted suckling, i.e. suckling for only some time during the day, is likely to be beneficial to calf growth and health while limiting losses in total and sellable milk production and limiting stress at weaning. The aim of this study was to propose suckling practices that achieve these balanced effects. We tested reuniting cows and calves for short periods before or after milking or for a half-day contact during the day between the morning and evening milkings. Reuniting cows and calves was generally performed only once a day with a view to limit farmers' labour while still allowing adequate calf growth (Ackerman et al., 1969; Saldana et al., 2019).

Material and methods

We conducted two trials at the Herbipôle experimental farm of the French National Institute for Agriculture, Food and Environment (INRAE)

(https://doi.org/10.15454/1.5572318050509348E12) located in Marcenat, France (45.30°N, 2.84°E, 1 080 m a.s.l.). All procedures were carried out in accordance with French Ministry of Agriculture guidelines on animal research and with all other applicable national and European regulations governing experiments with animals. All researchers responsible for the study (D. Pomiès, B. Martin, M. Bouchon, and I. Veissier) and all animal caretakers had adequate appropriate training, and the experimental farm is accredited for running experiments (C15-114-01).

Trial 1 was carried out between February and July 2017, and Trial 2 was carried out between February and July 2018. In Trial 1, two practices where calves had access to short-time CCC every day (**Before** and **After** milking) were compared to milk feeding with teat buckets and automatic milk feeder (**Control**). In Trial 2, a suckling practice where calves had access to day-time CCC every day (**Half-day**) was compared to artificial suckling practice (**Control**). Each practice was applied on a group of 14 dam–calf pairs (7 Holstein [**Ho**] and 7 Montbéliarde [**Mo**]). Within each trial, the 14 dam–calf pairs were balanced for lactation number (2.55 ± 1.68 in Trial 1, 2.71 ± 1.56 in Trial 2), date of calving (28 March ± 22 d in Trial 1, 17 March ± 14 d in Trial 2) and milk yield genetic index (84 ± 294 in Trial 1, 106 ± 205 in Trial 2). The groups were decided before calving; the sex of calves was therefore not balanced. In Trial 1, 78%, 29% and 50% of the calves were female in Before-, After- and Control-groups respectively and in Trial 2, 36% and 29% of the calves were female in the Half-day- and the Control-group respectively. Cows were milked in a 2 x 14 herringbone milking parlour (Delaval, France) twice a day at 07:00 am and 04:30 pm.

Animal management

Before weaning in Trial 1

144 The Control-calves were separated from their dams within a few hours (up to 6 h)
145 after birth. They received at least 2.0 L of fresh colostrum from a feeding bottle. If
146 there was no good-quality fresh colostrum available (< 24% Brix, measured by
147 refractometer), then good-quality thawed and reheated colostrum was provided. The
148 calves were housed in individual pens for 7–9 days and fed bulk milk twice a day
149 using teat buckets. After this period calves were group housed in a collective straw-
150 bedded pen of 60 m^2 with access to water and a hay rack until weaning. They were
151 fed bulk milk by an automatic feeder equipped with teats (Förster Technik Engen,
152 Germany), specific starter-age concentrate (from Centraliment factory, Aurillac,
153 France) distributed in a bowl within the same automatic feeder as for milk, and hay
154 (permanent grassland, first cut). Amount of milk provided to the calves was about
155 13% of their BW (12% to 15% depending on the age) during the first seven weeks of
156 life, and then the amount of milk was gradually reduced until weaning at about the
157 13^{th} week (Table 1). In the two remaining groups, the calves spent the first three days
158 after birth with their dams in a 20 m^2 individual calving pen or a 40 m^2 collective pen
159 for three cows and their calves, depending on pen availability. All pens were
160 equipped with water troughs. During these days, animal caretakers checked at least
161 twice a day if the calves suckled properly their dam. Then calves were separated and
162 accommodated in a collective pen until weaning and cows returned to the herd.
163 Before-calves had access to their dam in a specific collective pen facing the milking
164 parlour (90 m^2) for 20 min before the morning milking and 10 min before the evening
165 milking for the first two weeks, then only for 20 min before the morning milking. After-
166 calves had access to their dam in a cow pen for 2.5 h after the morning and evening
167 milkings for the first two weeks, then only for 2.5 h after the morning milking. The

168 calves were also fed concentrate by an automatic feeder. The calf feeding plan is
169 detailed in Table 1.

170 *Before weaning in Trial 2*

171 Control-calves were reared in the same way as those in Trial 1, except that the
172 amount of milk available in the automatic milk dispenser was 14% of calf BW during
173 the first seven weeks then decreased from 8% BW in Week 8 to 3% BW from week
174 10 (Table 1). Because there were fewer calves to be suckled by their dam in Trial 2
175 than in Trial 1, Half-day-calves spent the first five days after birth (and not only the
176 first three days as in Trial 1) alone with their dam in a straw-bedded 20 m^2 individual
177 calving pen (and never in a collective calving pen as sometimes done in Trial 1). The
178 calves received colostrum directly from their dam. The calves were then housed in a
179 collective straw-bedded pen next to the cowshed (50 m^2), from which they could see
180 their dams. From 07:30 am when cows came back from the milking parlour to 04:30
181 p.m., the separation gate between the calves' pen and the cowshed was left open so
182 that the calves could suckle their dams. Calves had free access to water, a hay rack
183 and a bucket with concentrate. The calf feeding plan is detailed in Table 1.

184 *Cow feeding in Trials 1 and 2*

185 The cows were fed ad libitum with a mixed ration (82% 1st-cut hay, 18% 2nd-cut hay
186 in Trial 1; 40% 1st-cut hay, 60% 2nd-cut hay in Trial 2) plus 5 kg/d of concentrates
187 (from Centraliment factory) distributed twice a day until early May (1.5 kg/d of protein
188 concentrate and 3.5 kg/d of energy concentrate in Trial 1; 1.0 kg/d of protein
189 concentrate and 4.0 kg/d of energy concentrate in Trial 2). From early May, the cows
190 went to pasture day and night, and received 2.0 kg of a pasture-specific concentrate
191 after each milking. During the two periods, cows had free access to water. In Trial 1,

192 the three groups of cows grazed together during the daytime and all calves stayed
193 inside the barn. In Trial 2, the two groups of cows grazed in two adjacent plots,
194 swapping every morning to ensure the same feeding, during the daytime. Half-day-
195 calves went to pasture with the cows, while Control-calves stayed inside the barn.

196 *Calf weaning in Trials 1 and 2*

197 Weaning took place in batches, every two weeks. The calves were weaned at a BW
198 of at least 100 kg, which was reached in average on Week 13 in Trial 1 (108 ± 3.9 kg)
199 and Week 11 in Trial 2 (114 ± 2.2 kg). On the day of weaning, the calves to be
200 weaned were moved to two collective pens [one for each group, 10 x 70 m] for one
201 week, and then to the same collective pen (Trial 2) or were moved directly to a
202 collective pen (Trial 1) due to lack of pen availability. After weaning calves and cows
203 could not see each other, but they could hear each other as they were housed in the
204 same cowshed. Post-weaning calves were fed concentrate and hay (Table 1).

205 ***Measurements***

206 *Trial 1*

207 Individual milk yield at parlour was measured at each milking using milk flow meters
208 (MM27BC, DeLaval, Tumba, Sweden). Individual milk samples of 30 mL were taken
209 on four consecutive milkings per week and analyzed at Agrolab's (Aurillac, France) to
210 determine milk fat and milk protein contents by mid-infrared spectroscopy. Milk SCC
211 were measured by epi-fluorescence on two consecutive milkings per week until 16
212 weeks after calving to calculate average individual milk yield at the parlour and milk
213 composition by week of lactation.

214 Calf BW was measured at birth then every Tuesday morning until 15 weeks of age to
215 calculate individual average daily gain (**ADG**) (*ID 300* scale, TRU-TEST; 0.5 kg
216 precision, up to 250 kg). Before- and After-calves were weighed just before and 20
217 min after joining the cows, and the measures served to estimate the individual milk
218 intake by suckled calves per week until weaning as the difference in BW after and
219 before suckling. Daily milk intake by Control-calves was recorded by the automatic
220 milk feeder until weaning.

221 Animal caretakers checked clinical signs on animals at least once a day, they applied
222 Standard Operating Procedures to cure the animal affected and recorded the
223 disorder and the treatment used in a sanitary logbook. The quality of the records was
224 checked once a week by one of the authors of the present paper (M. Bouchon).
225 Health disorders were sorted into reproductive disorders (metritis, retention of the
226 placental membrane, ovarian cysts, and vaginitis) and non-reproductive disorders
227 (mastitis, milk fever, lameness, etc.) for cows, and respiratory disorders (runny nose,
228 coughing, dyspnoea, etc.) and non-respiratory disorders (diarrhoea, umbilical
229 infection, etc.) for calves.

230 Around weaning (the day before weaning [Day 0], the day of weaning [Day 1], and
231 Day 2, Day 4 and Day 7 after weaning), the calves and their respective dams were
232 observed with continuous direct observations by two observers trained by an
233 experienced ethologist. The consistency between observers and the trainer was
234 checked during pilot observations. Observers checked that they recorded similarly
235 the behaviour. Observations started at 02.00 p.m. and lasted for 5 min to note
236 whether they vocalized *frequently* (seven vocalizations per min or more), *from time to*
237 *time* (from one to six vocalization per min), or not (zero vocalizations), with no
238 distinction between high or low pitched vocalizations. Calculations were thereafter

made of the daily percentage of animals that vocalized (frequently or from time to time), by group and by type of animal (calf or cow).

Trial 2

Milk yield, milk composition, health disorders and observations around weaning were measured in the same way as for Trial 1. Cow BW was measured at calving (on two consecutive days) and at weaning (*IRW ql* scale, DELAVAL; 1 kg precision, up to 15 000 kg). On the same dates, cow body condition score (**BCS**) was estimated on a scale of 0 (very thin cow) to 5 (very fat cow; Bazin, 1984). Calf BW was measured at birth then every Tuesday morning until 16 weeks of age to calculate individual ADG between birth and weaning and at three weeks before and after weaning (same scale as in Trial 1). Daily intake of milk by calves was not controlled.

From the beginning of March to the start of the grazing period (beginning of May), once a week, Half-day-cow-calf pairs were observed during the first hour after the morning milking by two trained observers who recorded all the calves' successful and refused suckling attempts from their dam or from other cows. To estimate the acceptance by cows of calves other than their own, we calculated the ratio between percentage of successful sucking attempts by their own calf and that by other calves. A ratio > 1 indicates that the cow accepts her calf more than another.

Statistical analyses

The data were analyzed using the MIXED procedure of the SAS 9.4 software package (SAS Institute Inc., Cary, NC). SCC were log10-transformed to achieve normal distribution. Individuals - cow or calf - were considered as statistical unit and used in the models as random factors. For milk yield, milk composition, cow BW and BCS, the model took into account the effects of practice (Control group and two CCC

groups in Trial 1; Control group and one CCC group in Trial 2), week of lactation (repeated factor, for milk yield and milk composition only), breed (Ho or Mo), parity (primiparous or multiparous) and interactions group × week, group × breed and group × parity as fixed factors. Date of calving as well as initial values at calving (milk yield index, fat content index, protein content index, and BCS) were used as covariates. For calf BW, ADG and daily milk intake, the model considered the effects of practice, week of age (repeated factor, for BW and milk intake only), breed, sex, and the interactions group × week, group × breed and group × sex as fixed factors., Date of birth and BW at birth were used as covariates. For all data, normality of residuals was checked using the Shapiro-Wilk test and their homogeneity was checked visually. To obtain best-fit models for each variable, fixed factors (other than group) and interactions with $P > 0.15$ were discarded using a manual stepwise backwards selection.

Frequency of health disorders and vocalizations around weaning was compared between groups using a Chi-square test. Significance was set at $P \leq 0.05$ and tendency at $0.05 < P \leq 0.10$. The ratio acceptance of other calves by cows was compared to 1 (no difference between own calves and others) using a Wilcoxon rank sum test. As the weaning took place between the 9th and the 13th week, the statistical analyses were carried out successively on 2 periods: before weaning (Weeks 1-8), with t-test for paired comparisons between groups in Trial 1, and after weaning (Weeks 14-16). Results are expressed as means and Standard Errors in tables and figures. In the text, averages of the differences between groups or breeds are reported.

Results

287 ***Trial 1***

288 The experiment was stopped for the After-group on 12 June 2017, when After-calves
289 were about 8 weeks of age (see the subsection headed *Cow and calf health* for
290 details). The results reported in Table 1 refer to Weeks 1 to 8 for all groups and to
291 Weeks 14 to 16 for Control- and Before-groups only.

292 *Milk yield at parlour*

293 During the first 8 weeks of lactation, Before-cows produced 12.5 kg/d less milk per
294 cow and After-cows produced 7.0 kg/d less milk per cow than Control-cows. The
295 difference was marked especially at morning milking in Before-cows (-10.3 kg/d;
296 Table 2). The difference in milk yield between Before- and Control-cows increased up
297 to 13.1 kg/d from Week 1 to Week 4, then it stabilized at 11.0 kg/d from Week 5 to
298 Week 12 (Figure 1). The difference in milk yield between After- and Control-cows
299 decreased by up to 6.3 kg/d from Week 1 to Week 4, then it stabilized at 4.5 kg/d
300 until the trial was stopped for After-cows on Week 8. Milk yield was higher for Ho
301 cows than Mo cows from Week 1 to Week 8 (+4.6 kg/d). There was no interaction
302 between breed and cow group on milk yield at parlour.

303 The estimated total milk yield of nursing cows – including the milk suckled by calves
304 (see below) – was lower than the milk produced by Control-cows, by 5.3 kg/d in
305 Before-cows and 4.0 kg/d for After-cows. The difference was especially marked on
306 Week 2, with Before- and After-cows producing 9.3 kg/d and 8.1 kg/d less than
307 Control-cows. The difference thereafter diminished and disappeared on Week 7.
308 From Week 14 to Week 16, milk yield of Before-cows increased but remained lower
309 than that of Controls (-5.2 kg/d).

310 *Milk composition at parlour*

311 During the first eight weeks of lactation, average milk fat content was lower for After-
312 cows compared to Control-cows (-0.47 percent point [pp]) or to Before-cows (-0.67
313 pp; Table 2). At morning milking, milk fat content was lower in Before-cows than in
314 the other groups, whereas at evening milking milk fat content was lower in After-cows
315 than in the other groups. A Group × Breed interaction was observed in both morning
316 and evening milking: in After-cows, milk fat content was lower in Mo cows than in Ho
317 cows (-0.45 pp, on average). Milk protein content was higher in Before-cows than in
318 the other groups (0.28 pp on average) and this difference was similar in morning and
319 evening milk. Milk protein content was higher in Mo cows than in Ho cows in all three
320 groups in morning and evening milk (+0.22 pp on average). Before- and After-cows
321 had about 30 000 somatic cells/mL of milk more than Control-cows, but this
322 difference was not significant. From Week 14 to Week 16, the differences in milk fat
323 content between Before- and Control-cows increased up to 0.28 pp and became
324 significant, whereas the difference in protein content decreased to 0.14 pp but stayed
325 significant. SCC was again higher in Before-cows than Control-cows (+75 000) but
326 the difference was still not significant.

327 *Milk intake by calves*

328 During their first eight weeks of life, Before-calves ingested more milk (+1.24 kg/d)
329 and After-calves ingested less milk (-3.03 kg/d) than Control-calves (Table 2), with no
330 overall between-breed difference but a significant breed × group interaction. Within
331 Before-calves, Ho ingested more milk than Mo (+1.20 kg/d) whereas within After-
332 calves, Ho ingested less milk than Mo (-1.04 kg/d). From birth to weaning, Before-
333 calves ingested 2.72 kg/d more milk than Control-calves; and within Before-calves,
334 Ho again ingested more milk than Mo (+1.13 kg/d).

335 *Calf growth*

From Week 1 to Week 8, After-calves had 42% less ADG and Before-calves 26% more ADG than Control-calves (Table 2). The BW difference between Control-calves and After-calves increased progressively from 2.5 kg to 13.9 kg (Figure 2). Because of this low growth and a number of health disorders (see under *Cow and calf health*), the experiment was stopped for the After-group. The BW difference between Before-calves and Control-calves was constant up to 6 weeks of age (+3.5 kg on average) and then became higher from Week 7 to Week 15 (+10.2 kg on average). From birth to weaning, Before-calves had 162 g/d higher ADG than Control-calves.

Cow and calf health

During the 16 weeks of the trial, the frequency of health disorders was not significantly different between groups of cows. Reproductive disorders occurred once in Before-cows and once in After-cows, and non-reproductive disorders occurred six times in Control-cows, seven times in Before-cows and four times in After-cows. We observed statistical difference between groups of calves both in respiratory ($P = 0.02$) and non-respiratory ($P = 0.001$) disorders. No disorders were observed in Control-calves. Three Before-calves and six After-calves were diagnosed with respiratory disorder due to bovine respiratory syncytial virus (BRSv). Despite medical treatment (anti-inflammatory drugs, vaccine against BRSv, and antibiotics to prevent complications), two Before-calves and four After-calves died. Four After-calves had episodes of diarrhoea, including two affected by the respiratory disorder. We decided to stop the experiment for the After-calves on 12 June due to the high calf morbidity and mortality and their low BW gain.

Vocalizations at weaning

As the trial was stopped prematurely for the After-group, observations at weaning were not performed. Control-calves vocalized mainly on Day 2 after weaning (75% of the calves; Figure 3). Before-calves started to vocalize earlier (92% on Day 1) and continued to vocalize later (75% on Day 4). On Day 7, only 17% of Before-calves were still vocalizing. Before-cows started to vocalize on Day 1, but less frequently than their calves (55%), and stopped vocalizing earlier than their calves (27% on Day 4). On Day 7, no Before-cows were vocalizing.

Trial 2

Milk yield at parlour

During the first 8 weeks of lactation, Half-day-cows produced 11.4 kg/d less milk than Control-cows (Table 3). The milk loss was distributed between morning (-4.4 kg/d) and evening (-7.3 kg/d) milkings. From Week 1 to Week 3, the milk yield of Half-day- and Control-cows increased by 7.9 kg/d, and the difference between Control- and Half-day-cows was about 9.4 kg/d (Figure 4). The milk yield of Control-cows stabilized at 28.6 kg/d from Week 3 to Week 11, and then started to decrease from Week 12 (Figure 4). The milk yield of Half-day-cows decreased significantly from Week 3 to Week 8 (-3.0 kg/d; $P = 0.02$) and then increased steadily to reach the same milk yield as Control-cows on Week 14 (25.7 kg/d). During the first 8 weeks of lactation, the loss in milk yield due to nursing was higher for Ho tan Mo cows especially at evening milking (Ho, -8.3 kg/d i.e. 72%; Mo, -6.8 kg/d i.e. -62%) whereas only a tendency was observed for daily milk yield (Ho, -14.6 kg/d i.e. -50%; Mo, -8.33 kg/d i.e. -34%).

Milk composition at parlour

382 During the first 8 weeks of lactation, milk fat content was lower in Half-day-cows than
383 Control-cows (-0.78 pp), with a similar difference between morning and evening milk
384 (Table 3). Conversely, milk protein content was higher in Half-day-cows than in
385 Control-cows (+0.13 pp). No significant difference in SCC was noticed despite higher
386 values in Before-cows (+36 000 cell/mL).

387 From Week 14 to Week 16, no difference was found on milk yield, milk composition
388 and milk SCC between Half-day- and Control-cows (Table 3).

389 *Body condition of cows*

390 At the time of calf weaning, Half-day- and Control-cows had similar BW (633 kg) and
391 BCS (1.53 points; Table 3).

392 *Calf growth*

393 Half-day- and Control-calves had similar BW until the end of the trial (Figure 5).
394 From birth to weaning, ADG was similar in Half-day- and Control-calves, and was
395 higher in Mo than in Ho calves (+176 g/d; Table 3). However, during the three weeks
396 before weaning ADG was higher in Half-day-calves than in Control-calves (+230 g/d).
397 During the 3 weeks after weaning, ADG was the same between groups and was
398 lower in Mo than in Ho calves (-222 g/d). The difference between Mo and Ho was
399 marked in Control-calves (-365 g/d; $P < 0.001$) whereas it was not observed in Half-
400 day-calves (-81 g/d; $P = 0.42$).

401 *Cow and calf health*

402 During the 16 weeks of Trial 2, the frequency of health disorders was not significantly
403 different between Half-day- and Control-cows. Reproductive disorders occurred five
404 times in Half-day-cows and two times in Control-cows, and non-reproductive

disorders occurred seven times in Half-day-cows and five times in Control-cows. In calves, there were no significant between-group differences in frequency of respiratory disorders (seven occurrences in Half-day-calves *vs*. five in Control-calves) or non-respiratory disorders (two occurrences in Half-day-calves *vs*. three in Control-calves). No calves died during Trial 2.

Vocalizations at weaning

Most of the Control-calves vocalized from Day 2 to Day 4 after weaning (Figure 3). Half-day-calves started vocalizing earlier than Control-calves (100% on Day 1) and continued vocalizing throughout the week (93% on Day 4, 43% on Day 7). All the Half-day-cows started vocalizing on Day 1, but tended to stop vocalizing earlier than their calves (64% *vs*. 93% on Day 4).

Acceptance of calves by cows

On average, the acceptance by Mo cows of calves other than their own was significantly higher than 1 (1.46 ± 0.14, $P < 0.05$). Conversely, the acceptance of another calf by Ho cows was not significantly higher than 1 (1.28 ± 0.14, $P > 0.05$).

Discussion

Here we tested three practices of restricted CCC that allowed suckling: two practices that allowed only short contacts during the day, i.e. just before (for 20 min/d) or after (for 2.5 h/d) the morning milking, and one practice that allowed a long period of free cow–calf contact (for 9 h/d) between the morning and evening milkings. First, we discuss the pro and cons of each practice before addressing common aspects in terms of milk production and weaning.

Suckling for 2.5 h immediately after milking fails to cover the calves' nutritional needs while significantly reducing the amount of sellable milk

We expected calves to be able to ingest the milk left after milking with minimal impact on milk yield at parlour. Allowing calves to suckle their dam for 2.5 h immediately after milking (group referred to as After) was thus tested as a way to minimize the impact of suckling on sellable milk. Under this practice, the cows yielded on average 29.0% less sellable milk than Controls. The calves however suckled little milk (3.0 kg/d). As a consequence, they had very low BW gain (half that of Control-calves) and were in poor health. We had to stop this suckling practice after eight weeks to avoid putting the calves at too much risk. When After-calves joined the cows, not enough milk may have remained in the udder. We conclude that there is no benefit in allowing calves to suckle for a limited time immediately after milking. If suckling takes place after milking, it seems more beneficial to reunite cows and calves later - e.g. 2 h after milking - and to keep them together until the calf has suckled (De Passillé et al., 2008).

Suckling for 20 min before milking satisfies the calves' nutritional needs but drastically reduces the amount of sellable milk

Allowing calves to suckle their dam for 20 min before milking (group referred to as Before) was tested here as a way to give calves a short period of access to large quantities of milk that should cover their nutritional needs. Indeed, during the first eight weeks, Before-calves ingested 20% more milk than the Control-calves that were provided milk from an automatic feeder (in quantity equivalent to 13% of their BW). Not all Control-calves ingested all the milk offered to them. Being able to suckle the dam seems thus to stimulate milk ingestion more than delivering milk by a feeder,

451 even when the feeder is equipped with teats. Control-calves had free access to a
452 single teat for the whole group, which may have limited the intake; we however did
453 not notice competition between calves probably due to the milk being available for
454 the whole day. Before-calves grew faster than Control-calves (ADG: +23.2% in
455 Before-calves), which confirms earlier findings that suckling is beneficial to calf
456 growth (e.g. Roth et al., 2009). This benefit may come from the higher amounts of
457 milk ingested or from the positive effect of suckling on calf metabolism (Uvnäs-
458 Moberg et al., 2001). We did not observe any improvement in the health of Before-
459 calves compared to Controls. Testing benefits on health however would require close
460 clinical examination of large numbers of calves, which was not the case in our study.

461 Milk release by cows during milking was strongly reduced when the cows suckled
462 their calves just before the morning milking (51.2% less milk than in Control-cows).
463 However, this decrease was still lower than that reported by Barth (2020) in cows
464 suckling their calves just before both daily milkings (71% less milk). In our
465 experiment, the reduction in milk yield was very marked at morning milking (75.5%
466 less milk), which was expected because the calves started to empty the udder before
467 milking, but was still visible at the evening milking (14.9% less milk).

468 ***Allowing cow–calf contact from morning to evening milking offers a good***
469 ***compromise between meeting calves nutritional requirements and preserving***
470 ***sellable milk***

471 To minimize the impact of suckling on the amount of milk collected at the milking
472 parlour while at the same time allowing calves to drink enough milk from their dam,
473 we tested a third practice that consisted of reuniting cows and calves for 9 h a day
474 between the morning and the evening milkings (group referred to as Half-day). In

475 parallel, we increased the amount of milk offered to Control-calves (14% BW),
476 because some of the Control-calves in Trial 1 may have not been provided enough
477 milk as some of them drank all that was offered. On average, the Half-day-cows
478 produced 42.4% less milk than Controls. One could expect no reduction at the
479 morning milking because the cows and calves were separated at night, but this was
480 not the case (reduction of 26.3%).

481 Half-day- and Control-calves had a similar growth, which suggests they ingested
482 similar amounts of nutrients.

483 ***Suckling reduces milk yield and affects milk composition in all scenarios***

484 In our experiments, suckling cows always yielded less milk at the milking parlour than
485 non-suckling cows: 28.7% less when the calves had access to the cows just after the
486 morning milking (for 2.5 h), 42.4% less when the calves had access to the cows
487 between milkings (for 9 h), and 51.2% less when they had access to the cows for a
488 short period (20 min) just before the morning milking. These reduced yields are
489 consistent with those reported in the literature: 24% less when suckling takes place
490 for 2 h after milking (de Passillé et al., 2008), and 43% less when the calves stay with
491 the dam between evening and morning milkings (Barth, 2020). As already reported
492 by Fröberg et al. (2005) and Barth (2020), the reduction in milk volume collected at
493 the milking parlour cannot be explained solely by the milk ingested by calves. Indeed,
494 in Trial 1 where milk ingested by calves was measured, the reduction of sellable milk
495 exceeded the amount of milk suckled by calves, and therefore total milk production
496 was still lower than that of Control-cows, by 21.7% in Before-cows and 16.5% in
497 After-cows. The oxytocin release at milking is less marked when cows suckle their
498 calves, either when suckling occurs just before milking (Lupoli et al., 2001) or after

499 milking (de Passillé et al., 2008). This could explain partly why all suckling cows in
500 this experiment released less milk at the milking parlour even when their calves drank
501 very little milk. Nevertheless, the decreased total milk production occurred only at the
502 time of the lactation peak, which was absent in Before- and After-cows, whereas
503 interestingly, total milk production of Control- and Before-cows was similar after
504 Week 8 although calves were still suckling. This observation, never reported before,
505 deserve to be confirmed in further trials where milk ingestion by suckled calves is
506 measured.

507 In the Half-day-cows, the higher reduction in milk obtained at the parlour in Ho cows
508 compared to Mo cows - especially at evening milking - could be at least partly
509 explained by their slightly higher acceptance of calves other than their own.
510 Moreover, the higher milk yield of Ho cows may make them more attractive to calves.

511 After separation from their calves, the milk yield at parlour increased in all suckling
512 cows. Half-day-cows reached the milk yield of Control-cows within a week, whereas
513 Before-cows never managed to ‘catch up’ with Control-cows (-25.2% from week 14 to
514 16). Similar observations were reported by Barth (2020) in cows suckling their calves
515 before milking. Cows from some breeds (like Salers or Zebu-Holstein) can only be
516 milked if the calves first initiate milk release by a short suckling (Fröberg et al., 2007;
517 Guiadeur et al., 2011). We suspect that this same kind of process sets in when dairy
518 cows get used to suckle just before milking, making it more difficult to milk them at
519 the parlour when suckling ends (Tančin & Bruckmaier, 2001).

520 Suckling had effects on milk composition. Milk fat content decreased when cows
521 suckled after milking or between milkings and increased when they suckled just
522 before milking. When suckling occurs after milking, the calves mainly consume the
523 residual milk, which has a high fat content, whereas when suckling occurs before

524 milking, the calves suckle the cisternal milk, which has a low fat content (Rico et al.,
525 2014). These variations in turn affect the fat content of the milked milk. Milk protein
526 content increased in Before- and Half-day-cows, which confirms previous results
527 from Margerison et al. (2002) and Barth (2020). Milk protein content increases when
528 the energy balance of the cows is higher (Coulon & Rémond, 1991). Because
529 suckling cows produced less total (suckled + milked) milk and presumably had similar
530 feed intake, their energy balance was probably higher than that of Control-cows.

531 Suckling is thought to improve udder health (Fröberg et al., 2005; Margerison et al.,
532 2002). However, in our studies we never found difference in SCC or frequency of
533 mastitis between CCC practices and Controls. As already noticed by Johnsen et al.
534 (2016) in their review on CCC, the beneficial effect of suckling on cows' udder health
535 is not always observed.

536 ***Weaning is stressful for both calves and cows***

537 All calves vocalised at weaning. Weaning has a psychological component due to the
538 associated changes in environment: separation from the dam for calves suckling their
539 dam, changes in accommodation (for all calves in our experiments), and changes in
540 feeding routines (Jasper et al., 2008; Veissier et al., 1989; Weary et al., 2008).
541 Almost all the Before-calves and Half-day-calves vocalized on the day of weaning
542 whereas Control-calves vocalized about 24 h later. Vocalizations can be at least
543 partly due to hunger since calves vocalize less when they have access to milk after
544 the separation from their dams (Johnsen et al., 2018). According to Thomas et al.
545 (2001), vocalizations in the first hours after weaning are due to the separation from
546 the dam, and vocalizations later on are due to hunger. This suggests that at weaning,
547 Control-calves reacted to the lack of milk whereas Before- and Half-day-calves

548 reacted also to the separation from the dam and were stressed for longer as they
549 vocalised for several days.

550 The cows vocalized for two days after separation, either from time to time (Before-
551 cows) or more frequently (Half-day-cows). In our study, calves were weaned
552 according to their age and were therefore removed not all at the same time. As most
553 cows suckled other calves after their own calves had been weaned, we can rule out
554 the hypothesis of vocalizations reflecting discomfort produced by a distended udder
555 due to lack of suckling after weaning. Cows establish strong bonds with their
556 offspring, and if bonding is followed by an abrupt separation, the cows manifest
557 stress reactions such as restlessness and vocalizations (Flower & Weary, 2001;
558 Weary & Chua, 2000). Cow vocalizations at weaning are thus likely to reflect stress
559 experienced by cows due to separation from their calves.

560 In conclusion, a short cow–calf contact (2.5 h) immediately after milking does not
561 provide enough milk for the calves, whereas a short contact (20 min) immediately
562 before milking strongly decreases the amount of sellable milk. Allowing a long period
563 of CCC (9 h) between morning and evening milkings makes good compromise
564 between sellable milk and calf growth. Contrary to what was expected, weaning
565 induces a stress in cows and calves that have experienced restricted suckling. To
566 promote animal welfare by allowing cow–calf contact and suckling, it is therefore
567 necessary to reduce weaning-related stress. Restricted suckling probably needs to
568 be followed by a two-step weaning process by using nose-flaps for a few days before
569 the separation or by using a fence-line separation to enable continued visual and
570 some tactile contact after weaning before complete separation (Haley et al., 2005;
571 Johnsen et al., 2018; Loberg et al., 2008; Price et al., 2014).

572 The reduction in sellable milk and in its fat content due to suckling will affect the
573 revenue of the farmer from the milk production. Suckling however may affect
574 positively calves' growth and health, cows' career, farmer workload, etc. All these
575 effects should be considered to assess the net impact on farmers' income. If the
576 reduction in sellable milk is not balanced by benefits then the opportunity to generate
577 added value for this practice should be investigated, considering the demand for
578 certification aiming at identifying "animal welfare" practices or "husbandry systems"
579 traceability (Beaver et al., 2020; Janssen et al., 2016).

580 **Ethics approval**

581 All procedures were carried out in accordance with French Ministry of Agriculture
582 guidelines on animal research and with all other applicable national and European
583 regulations governing experiments with animals. All researchers responsible for the
584 study (D. Pomiès, B. Martin, M. Bouchon, and I. Veissier) and all animal caretakers
585 had adequate appropriate training, and the experimental farm is accredited for
586 running experiments (C15-114-01). The two trials did not require approval by an
587 ethics committee.

588 **Data and model availability statement**

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

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Declaration of interest

None.

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Table 1

Feeding plans used for the three groups of calves in Trial 1 and the two groups of calves in Trial 2 during the first 16 weeks of age.

			Weeks of age															
Trial	Group[1]	Feed[2]	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	Control	Milk[3] (kg/d)	6.0	6.0	7.0	8.0	8.0	8.0	8.0	7.0	6.0	5.0	4.0	3.0	Weaning			
		Concentrate[4] (kg/d)	0.0	0.0	0.2	0.2	0.3	0.5	0.7	0.9	1.1	1.4	1.7	2.0	~2.0	~2.0	~2.0	~2.0
		Hay[5]	0.0	0.0	Ad libitum ------													
	Before	Milk (suckling)[6]	Twice a day		During 20 min before the morning milking ------										Weaning			
		Concentrate (kg/d)	0.0	0.0	0.2	0.2	0.3	0.5	0.7	0.9	1.1	1.4	1.7	2.0	~2.0	~2.0	~2.0	~2.0
		Hay	0.0	0.0	Ad libitum ------													
	After	Milk (suckling)	Twice a day		For 2.5 hours after the morning milking ------										Weaning			
		Concentrate (kg/d)	0.0	0.0	0.2	0.2	0.3	0.5	0.7	0.9	1.1	1.4	1.7	2.0	~2.0	~2.0	~2.0	~2.0
		Hay	0.0	0.0	Ad libitum ------													
2	Control	Milk (kg/d)	6.0	7.0	9.0	10.0	10.0	10.0	9.0	7.0	5.0	3.0	Weaning					
		Concentrate (kg/d)	0.0	0.0	0.2	0.4	0.6	0.9	1.2	1.5	1.8	2.0	~2.0	~2.0	~2.0	~2.0	~2.0	~2.0
		Hay	0.0	Ad libitum ------														
	Half-day	Milk (suckling)	24 h/d	From morning to evening milking ------									Weaning					
		Concentrate (kg/d)	0.0	Ad libitum ------									~2.0	~2.0	~2.0	~2.0	~2.0	~2.0
		Hay	0.0	Ad libitum ------														

[1] Control-calves were separated from their dam at birth; Before-calves were able to suckle their dam for 20 min before the morning milking; After-calves were able to suckle their dam for 2.5 h after the morning milking; Half-day-calves were able to suckle their dam for 9 h between the morning and evening milkings.

[2] All quantities are expressed as fed per day.

[3] Bulk milk distributed individually by an automatic feeder.

[4] Starter-age concentrate distributed individually by an automatic feeder (Trial 1 and Control group in Trial 2) or in a collective bucket (Half-day-group in Trial 2).

[5] Permanent grassland hay (first cut) distributed in a rack.

[6] Milk available by suckling dams during specific periods.

Table 2

Milk production from cows and growth of calves in Trial 1.

	Group[1]			Breed[2]			*P-value*[3]		
	Control	Before	After	Ho	Mo	SEM	Group	Breed	Group × Breed
Week 1 to week 8[4]									
Milk yield (kg/d)	24.4[c]	11.9[a]	17.4[b]	20.2	15.6	0.79	<0.001	<0.001	
Morning milk yield (kg/d)	14.4[c]	4.1[a]	11.6[b]	11.1	8.95	0.46	<0.001	<0.001	
Evening milk yield (kg/d)	9.85[c]	8.38[b]	5.91[a]	9.13	6.97	0.35	<0.001	<0.001	
Milk fat content (%)	3.58[b]	3.78[b]	3.11[a]	3.55	3.44	0.08	<0.001	0.132	0.079
Morning milk fat content (%)	3.12[b]	2.64[a]	2.92[b]			0.08	<0.001		0.055
Evening milk fat content (%)	4.23[b]	4.24[b]	3.38[a]			0.08	<0.001		0.028
Milk protein content (%)	2.97[a]	3.27[b]	3.00[a]	2.98	3.19	0.04	<0.001	<0.001	
Morning milk protein content (%)	2.98[a]	3.32[b]	3.01[a]	2.94	3.21	0.03	<0.001	<0.001	
Evening milk protein content (%)	2.97[a]	3.26[b]	2.96[a]	2.97	3.15	0.04	0.001	0.001	0.103
Milk SCC (log_{10}/mL)	4.64	4.88	4.87			0.11	0.186		
Milk ingested by calf (kg/d)	6.00[b]	7.24[c]	2.97[a]			0.23	<0.001		0.004
ADG until 8 weeks of age (g/d)	587[b]	740[c]	340[a]	493	617	40.1	<0.001	0.012	
Week 14 to week 16[5]									
Milk yield (kg/d)	20.4	15.3				0.85	<0.001		
Milk fat content (%)	3.47	3.75				0.06	0.004		
Milk protein content (%)	2.84	2.98		2.84	2.97	0.04	0.035	0.049	
Milk SCC (log_{10}/mL)	4.71	4.91		5.05	4.57	0.14	0.351	0.026	
Milk ingested until weaning[6] (kg/d)	5.63	8.35		7.31	6.84	0.20	<0.001	0.063	0.018
Calf ADG until weaning (g/d)	699	861				35.6	0.004		

Abbreviations: SCC = somatic cell count; ADG = average daily gain.

[1] In Control-group, calves were separated from their dam at birth; in Before-group, calves were able to suckle their dam for 20 min before the morning milking; in After-group, calves were able to suckle their dam for 2.5 h after the morning milking.

[2] Each group consisted of 7 Holstein (Ho) and 7 Montbéliarde (Mo) cow-calf pairs.

[3] Adjusted values and *P-values* by group (Control, Before, After), breed (Ho, Mo), and group × breed interactions.

[4] When all Before- and After-calves could suckle their dam.

[5] When all calves were separated from their dam.

[6] Weaning took place when the calves weighed at least 100 kg.

[a,b] Values within a row with different superscripts differ significantly at $P<0.05$.

820 **Table 3**

821 Milk production, body condition of cows and growth of calves in Trial 2.

	Group[1]		Breed[2]			*P-value*[3]		
	Control	Half-day	Ho	Mo	SEM	Group	Breed	Group × Breed
Week 1 to week 8[4]								
Milk yield (kg/d)	26.9	15.5			1.19	<0.001		0.092
Morning milk yield (kg/d)	16.7	12.3			0.88	0.001		
Evening milk yield (kg/d)	10.8	3.54			0.37	<0.001		0.052
Milk fat content (%)	3.84	3.06			0.13	<0.001		
Morning milk fat content (%)	3.46	2.96			0.15	0.024		
Evening milk fat content (%)	4.38	3.22	3.97	3.63	0.10	<0.001	0.023	0.106
Milk protein content (%)	2.98	3.11			0.04	0.034		
Morning milk protein content (%)	2.99	3.11			0.04	0.058		
Evening milk protein content (%)	2.98	3.09			0.05	0.115		
Milk SCC (log_{10}/mL)	4.68	4.92	4.94	4.67	0.11	0.115	0.087	
Week 14 to week 16[5]								
Milk yield (kg/d)	23.7	23.1	24.3	22.5	0.80	0.542	0.116	
Milk fat content (%)	3.33	3.39			0.05	0.387		
Milk protein content (%)	2.88	2.98			0.04	0.142		
Milk SCC (log_{10}/mL)	4.90	4.85			0.12	0.755		
Week 1 to weaning[6]								
Cow BCS at weaning (0-5 scale)	1.52	1.54	1.45	1.62	0.11	0.852	0.108	
Cow BW at weaning (kg)	633	639			8.50	0.617		
Calf ADG until weaning (g/d)	943	929	848	1024	36.5	0.779	0.004	
Calf ADG 3 weeks before weaning (g/d)	1176	1406	1208	1374	60.1	0.015	0.111	

Calf ADG 3 weeks after weaning (g/d)	510	410	571	349	44.7	0.136	0.007	0.034

Abbreviations: SCC = somatic cell count; BCS = body condition score; ADG = average daily gain.

[1] In Control-group, calves were separated from their dam at birth; in Half-day-group, calves were able to suckle their dam for 9 h between morning and evening milkings.

[2] Each group consisted of 7 Holstein (Ho) and 7 Montbéliarde (Mo) cow-calf pairs.

[3] Adjusted values and *P-values* by group (Control, Half-day), breed (Ho, Mo), and group × breed interactions.

[4] When all Half-day-calves could suckle their dam.

[5] When all calves were separated from their dam.

[6] Weaning took place when the calves weighed at least 100 kg.

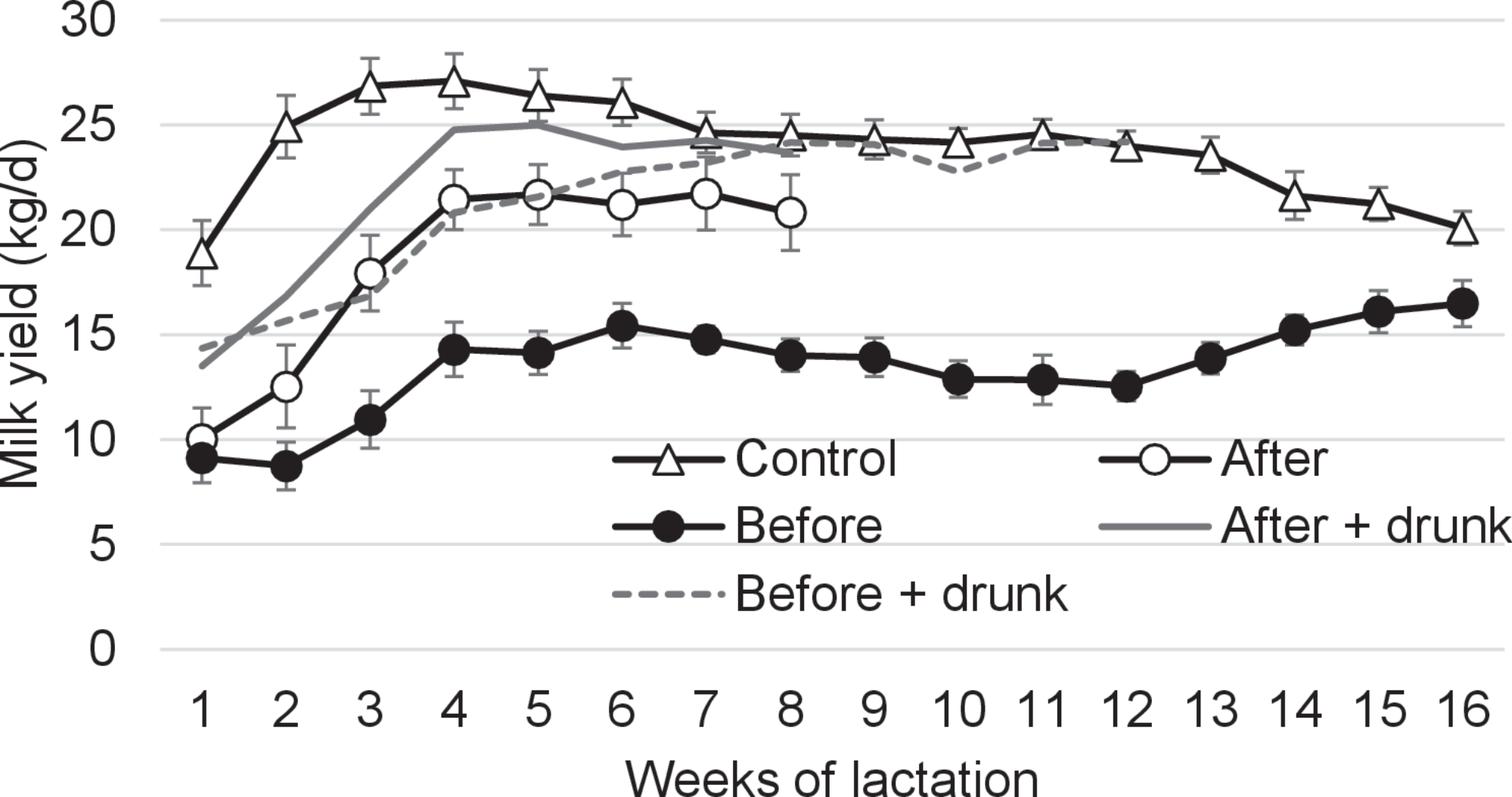
Figure 1 Daily milk yield at the parlour for the three groups of cows in Trial 1, by week of lactation (means and SE of raw data). In Control-group, calves were separated from their dam at birth; in Before-group, calves were able to suckle their dam for 20 min before the morning milking; in After-group, calves were able to suckle their dam for 2.5 h after the morning milking. Weaning took place when the calves weighed at least 100 kg. Each group consisted of 7 Holstein (Ho) and 7 Montbéliarde (Mo) cow-calf pairs. The grey lines represent the sum of the daily milk yield at parlour of cows and the milk drunk by calves (Before and After groups).

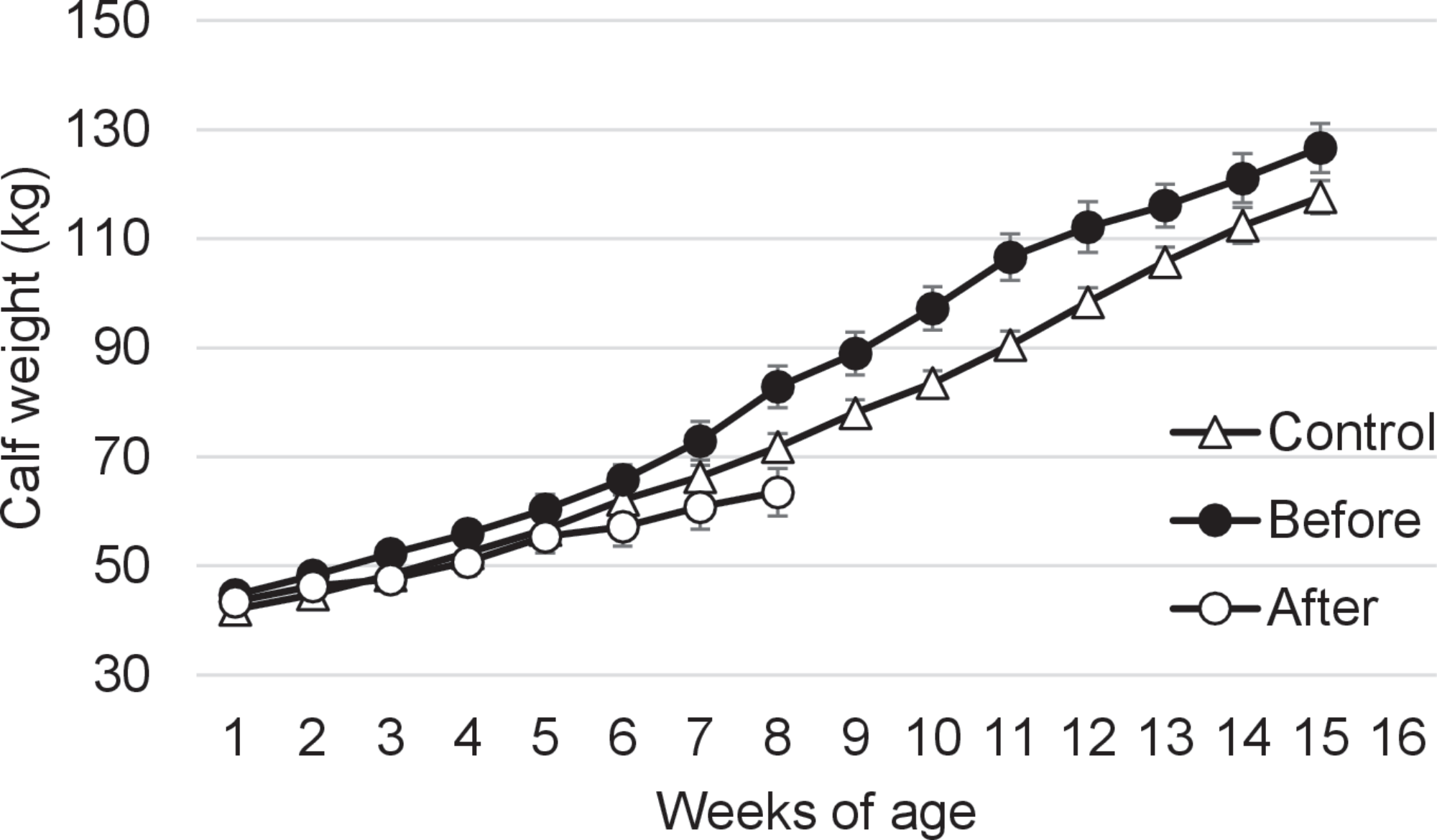
Figure 2 Body weight of the calves in Trial 1 by week of age (means and SE of raw data). Control-calves (n = 14) were separated from their dam at birth, Before-calves (n = 14) were able to suckle their dam for 20 min before the morning milking, and After-calves (n = 14) were able to suckle their dam for 2.5 h after the morning milking.

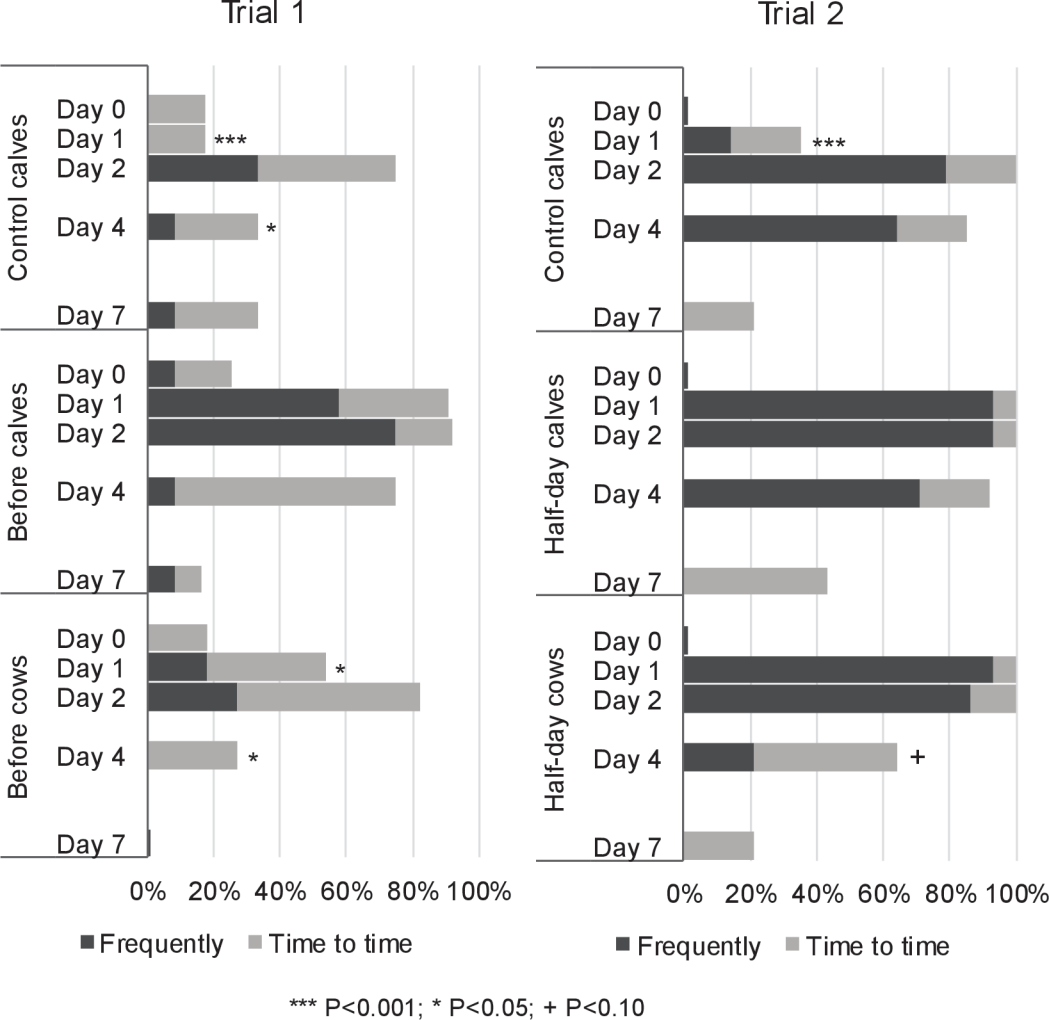
Figure 3 Percentage of animals that vocalized (frequently or from time to time) during one week around weaning (on Day 1) in Trial 1 and in Trial 2. Control-calves (n = 12 in Trial 1 and 14 in Trail 2) were separated from their dam at birth, Before-calves (n = 12) were able to suckle their dam for 20 min before the morning milking, and Half-day-calves (n = 14) were able to suckle their dam for 9 h between the morning and evening milkings. Chi-square test comparing per-day data with Before-calves in Trial 1 and with Half-day-calves in Trial 2.

Figure 4 Daily milk yield at the parlour for the two groups of cows in Trial 2, by week of lactation (means and SE of raw data). In Control-group, calves were separated from their dam at birth, and in Half-day-group calves were able to suckle their dam for 9 h between the morning and evening milkings. Weaning took place when the calves weighed at least 100 kg. Each group consisted of 7 Holstein (Ho) and 7 Montbéliarde (Mo) cow-calf pairs.

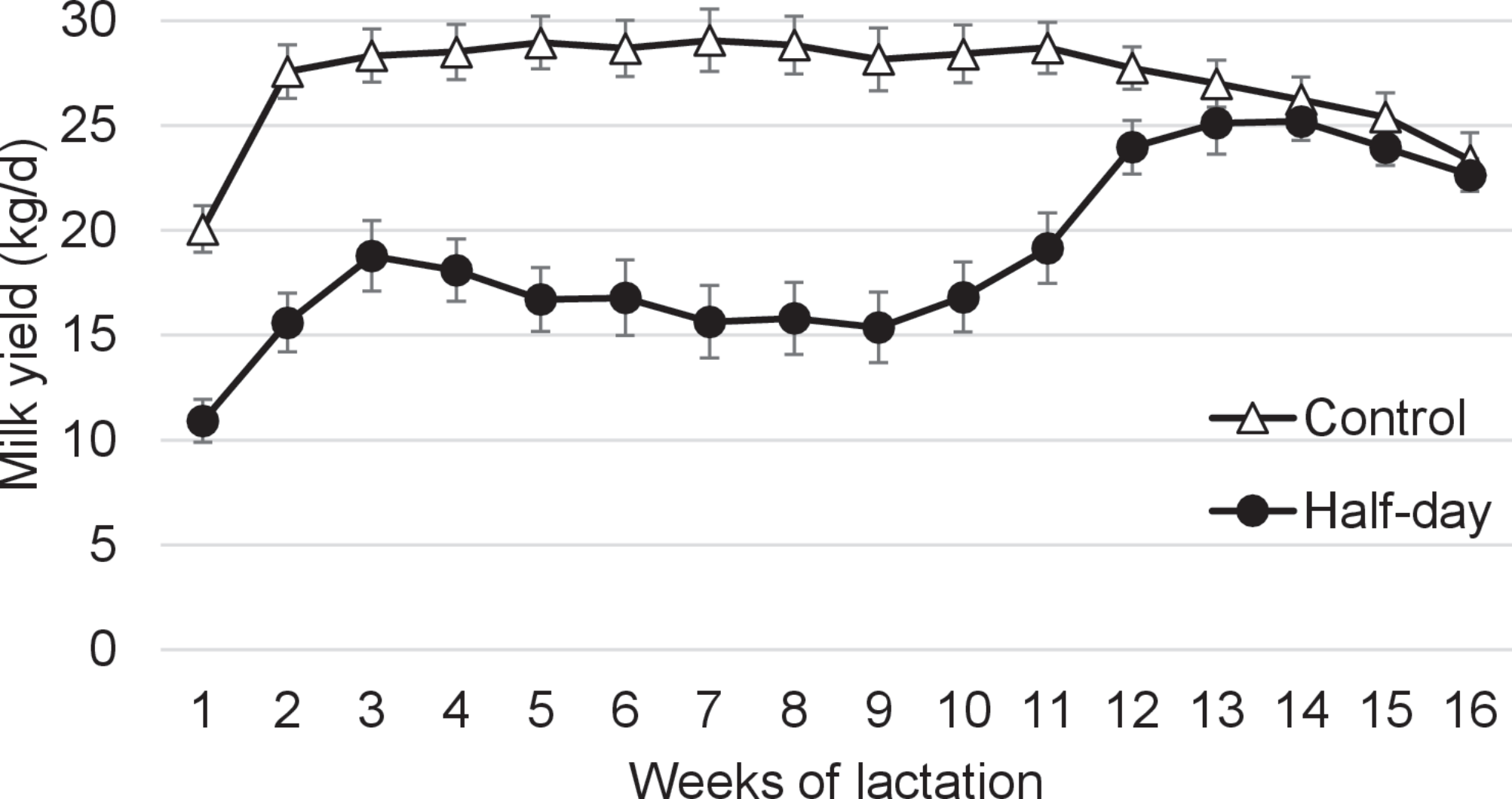
Figure 5 Body weight of the calves in Trial 2 by week of age (means and SE of raw data). Control-calves (n = 14) were separated from their dam at birth and Half-day-calves (n = 14) were able to suckle their dam for 9 h between the morning and evening milkings.

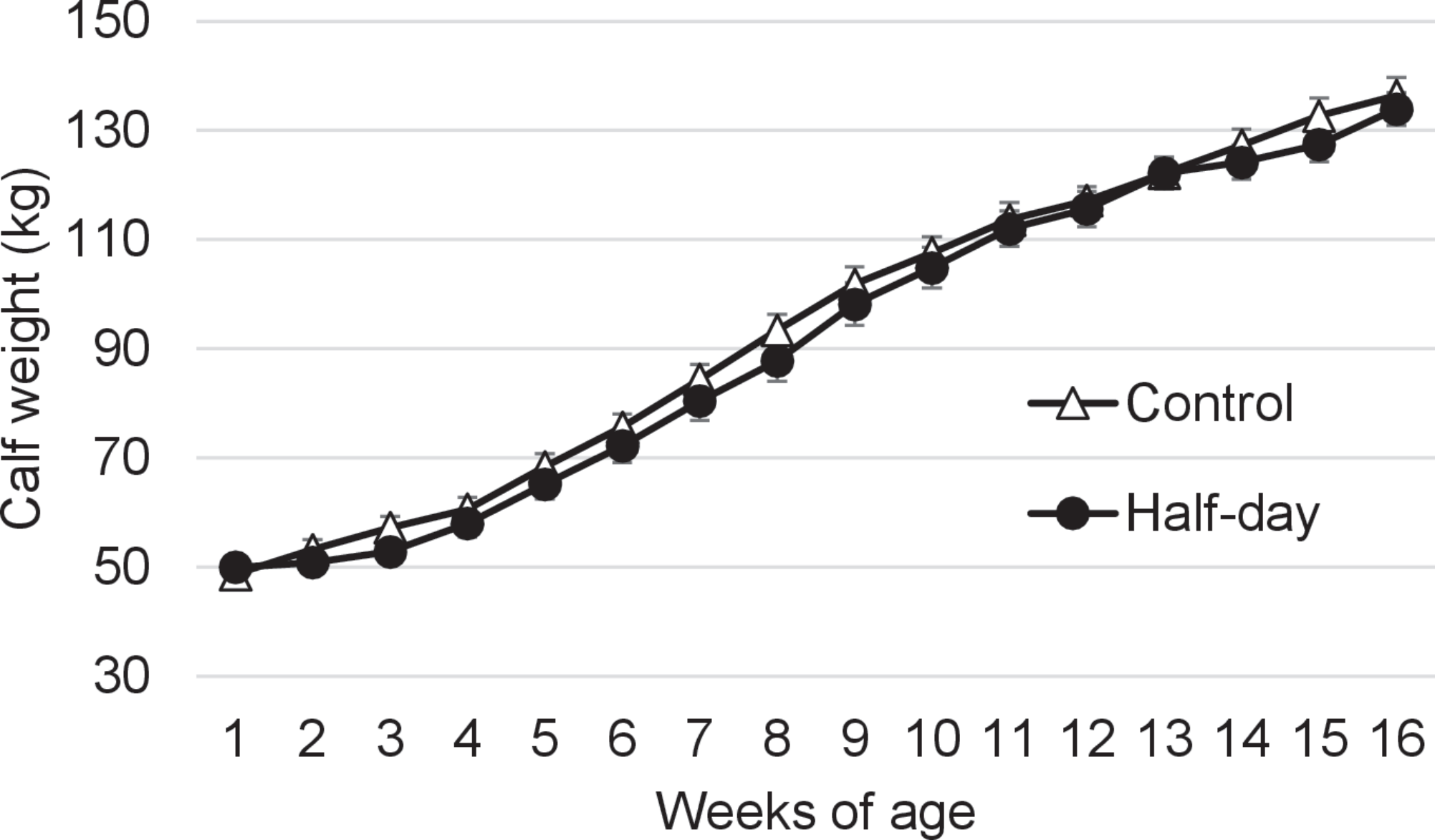

30
25
20
15
10
5
0
Milk yield (kg/d)
Control
After
Before
After + drunk
Before + drunk
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Weeks of lactation


150
130
110
90
70
50
30
Calf weight (kg)
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Weeks of age
Control
Before
After



*** P<0.001; * P<0.05; + P<0.10


Milk yield (kg/d)
30
25
20
15
10
5
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Weeks of lactation
Control
Half-day


150
130
110
90
70
50
30
Calf weight (kg)
Control
Half-day
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Weeks of age