Journal of Dairy Research

cambridge.org/dar

Growth rate and behaviour in separated, partially separated or non-separated kids and the corresponding milk production of their mothers

Madeleine Högberg[1], Louise Winblad von Walter[1], Eva Hydbring-Sandberg[1], Björn Forkman[2] and Kristina Dahlborn[1]

[1]Department of Anatomy, Physiology and Biochemistry, Faculty of Veterinary Medicine and Animal Science, Swedish University of Agricultural Sciences, SE-750 07 Uppsala, Sweden and [2]Department of Veterinary and Animal Science, Section of Animal Welfare and Disease Prevention, University of Copenhagen, 1870 Frederiksberg C, Denmark

Research Article

Cite this article: Högberg M, Winblad von Walter L, Hydbring-Sandberg E, Forkman B and Dahlborn K (2021). Growth rate and behaviour in separated, partially separated or non-separated kids and the corresponding milk production of their mothers. *Journal of Dairy Research* **88**, 381–387. https://doi.org/10.1017/S0022029921000789

Received: 14 December 2020
Revised: 2 August 2021
Accepted: 23 August 2021
First published online: 23 December 2021

Keywords:
Caprine goat welfare; growth rate; milk production; rearing system

Author for correspondence:
Kristina Dahlborn,
Email: kristina.dahlborn@slu.se

Abstract

We address the hypothesis that keeping kids and mothers together would have positive effects on the milk composition of the mother and the behaviour of the kids. Kids were either permanently separated (SEP), daily separated between 7.30 and 15 h (DAY-SEP) or kept with mothers 24 h/d (NON-SEP). The NON-SEP kids were only allowed to suckle one teat. All kids had similar growth rate throughout the study (lactation days 5–70). DAY-SEP kids spent 24% of their time with their mother at both ages. NON-SEP spent only 15% of the time with their mothers at 2 weeks of age and this increased to 28% at 2 months of age. NON-SEP kids showed more hiding behaviour at 2 weeks and SEP were more active alone, at both 2 weeks and 2 months, compared to the other treatments. The mean available milk yield and fat concentration were higher in DAY-SEP goats (2420 g ± 119 g and 4.9 ± 0.1%) compared with NON-SEP goats (2149 ± 79 g and 4.4 ± 0.1%). There were no differences between DAY-SEP and NON-SEP goats in total protein, lactose, or casein concentrations. Based on these data it was estimated that 7.1 kg milk was needed to produce 1 kg semi-hard cheese in DAY-SEP goats and 7.5 kg in NON-SEP goats, respectively. When comparing milk yield and composition between udder halves, the milk yield was, as expected, higher from the machine milked teat than from the suckled one in the NON-SEP goats but there was no difference between right and left udder halves in DAY-SEP goats. Milk fat concentration varied between teats at morning and afternoon milkings in NON-SEP goats, but there was no difference in milk fat between udder-halves in DAY-SEP goats. In conclusion, the kid growth rate was similar in all treatments, however, an altered behaviour was seen in permanently separated kids (SEP). The results show that it is possible to have a high milk yield and fat concentration with one kid together with the dam.

Dairy goats can be kept in intensive, semi-intensive or extensive management systems (FAO, 2014). In intensive systems, which are most common in industrial countries, early weaning of the offspring is customary (Miranda de la Lama and Mattiello, 2010) since it is often argued that early separation is the best way to get the largest amount of milk for processing and consumption. Intensification in the dairy sector gives less opportunity for animals to express natural behaviour and early separation of mother and offspring is known to impair the welfare of the animals (Miranda de la Lama and Mattiello, 2010). Earlier separation can be a stressful event for both goats and kids (Boivin and Braadstad, 1996; Bergamasco *et al.*, 2005; Newberry and Swanson, 2008; Miranda de la Lama and Mattiello, 2010; Winblad von Walter *et al.*, 2010), which often leads to reduced growth rate in the kids (Miranda de la Lama and Mattiello, 2010). The opportunity to express natural behaviour, in this case by rearing dams and kids together for a longer period, improves well-being and animal welfare (Hernandez *et al.*, 2007). Suckling is considered a positive situation, whereas abrupt and early separation of mother and offspring may have negative consequences (Newberry and Swanson, 2008). In semi-intensive and extensive systems, goats and kids can be kept together for longer periods and the dams are both milked and suckled simultaneously. In this study, we have translated the terminology presented by Sirovnik *et al.* (2020) when possible. The first aim of this study was to investigate growth and behaviour in artificially reared, early-separated kids (SEP), partially separated kids (contact allowed overnight, called daily separated kids or DAY-SEP) and full goat-kid contact, called non-separated kids or NON-SEP.

Hannah Dairy Research Foundation

CAMBRIDGE UNIVERSITY PRESS

It has been shown that keeping mother and offspring together can influence saleable milk production and cheese yield positively in dairy sheep (Knight *et al.*, 1993; McKusick *et al.*, 2001, 2002; Rassu *et al.*, 2015) and goats (Högberg *et al.*, 2016). These systems are especially appropriate for high yielding animals as the offspring normally cannot empty the udder (Marnet and Komara, 2008) and Delgado-Pertinez *et al.* (2009a, 2009b) such that large amounts of milk are left for human consumption.

During cheese production both milk yield and composition are of great importance, since casein (protein) and fat concentration affects both quality and yield of the curd (Diaz *et al.*, 1999; Clark and Sherbon, 2000; Soryal *et al.*, 2005). Swedish goats generally have a high milk production but with low concentrations of fat and protein (Högberg, 2011). According to the Swedish Goat Breed Association, it takes about 10 kg of milk to produce one kg of cheese. Högberg *et al.* (2016) showed that in systems with partial goat-kid contact, suckling before machine milking increased milk fat concentration compared to goats machine milked before suckling, and that goats kept with their kids for 16 h/d had higher milk fat concentration, casein concentration and curd yield compared with goats kept together with their kids for 8 h/d.

Suckling and frequent milking during early lactation improves mammary development by increasing both mammary proliferation and differentiation of mammary cells in goats (Wilde *et al.*, 1987; Knight and Wilde, 1993). The mother–young-bond has a very strong effect on the regulation of hormones involved in lactation, and interruption of the maternal–young-bond immediately after birth can result in negative effects on lactation persistency, and less effective oxytocin release during milking (Marnet and McKusick, 2001). Oxytocin-mediated milk ejections are necessary for a complete emptying of the udder, which also further stimulates milk secretion positively (Bruckmaier, 2005). Studies in goats (Olsson and Högberg, 2008) and ewes (Marnet and Negrão, 2000) confirm that oxytocin levels in plasma increase more during nursing/suckling than during milking. Also, higher milk yields were obtained in goats during suckling compared to machine milking (Delgado-Pertinez *et al.*, 2009a, 2009b).

There is substantial evidence that milk production is regulated by local factors within the mammary gland, as well as by systemic factors (Wilde *et al.*, 1995). In a review by Stelwagen (2001) it was concluded that the increase seen in milk yield, when milking frequency is increased in only one teat, is due to local mammary factors regulating the milk synthesis in each gland independently of each other. To investigate how suckling and milking influence milk production, it is necessary to compare suckled teats and milked teats separately. Therefore, in the present study NON-SEP kids were kept with their mothers permanently but they were only allowed to suckle one teat while the other was covered with a bra to prevent suckling. By this half udder system, samples were taken from machine milked and suckled teats separately. DAY-SEP kids (the other treatment in the present study) were allowed to suckle both teats but samples were collected from left and right udder half separately.

The aim of the present study was first to compare the behaviour of kids either artificially reared (SEP), daily separated kids with partial goat-kid contact (DAY-SEP) or kids with full goat-kid contact (NON-SEP). The second aim was to compare the saleable milk production from the groups. The third aim was to investigate how milk yield and composition were affected by suckling and machine milking. The hypothesis was that keeping goats and kids together would increase animal welfare and have a positive effect on the milk composition.

Material and methods

Animals, housing and management

Before experiments, twelve goats, 2–4 years old, of the Swedish domestic breed *(Capra hircus)* were kept in an indoor free range stall (10 × 7 m) with straw and shavings as bedding material (including large plastic boxes and tables for enrichment and hideouts), at the Swedish University of Agricultural Sciences, Uppsala, Sweden. Hay, water and mineral licks were available *ad libitum* and room temperature was 17 ± 1°C. All goats gave birth over an interval of slightly more than one month. After parturition, all kids ($n = 22$) stayed together with their mothers in the home pen and suckled freely for 4 d during the colostrum period. The female goat kids were dehorned at 2–4 weeks of age. Before the experiments started, all goats were well adapted to handling and accustomed to the experimental procedures, performed by the same experienced researchers and technicians. The Local Ethical Committee, Uppsala, Sweden, approved the care of the animals and the experimental procedures (C36/9).

Before parturition, the goats were randomly assigned into two treatments: Partial goat-kid contact, DAY-SEP (goats and kids were kept together but separated daytime between 7 : 30 and 15 : 00) and full goat-kid contact, NON-SEP (no separation, goats and kids were together for 24 h). It was decided that the goats should be kept with one kid, and preferably a female goat kid since female kids are commonly recruited to the herd. Therefore, one kid was allocated into the same treatments as their mothers (DAY-SEP, NON-SEP) and the rest of the kids were allocated to a third treatment where they were permanently separated from their mother (SEP) and artificially reared. A total of 11 goats and 22 kids participated in the study. Further details of how the kids were allocated to the treatments are described in the online Supplementary File and in (Winblad von Walter *et al.*, 2021).

Experimental procedures

A total of ten kids, nine males and one female, were artificially reared and separated from their mothers permanently on day 5 (SEP). The kids were fed goat milk from the herd three times daily with a self-feeder and were kept in a pen, 4.5 × 3 m (including large plastic boxes and tables for enrichment and hideouts), in the same animal room as the goats home pen.

Six kids, three of each gender, had partial goat-kid contact by separating them during daytime between 7 : 30 and 15 : 00 h, while the goats were moved to an adjustment room next door (DAY-SEP). There, the goats were kept in a loose housing pen and had free access to hay, water and mineral licks. At 15 : 00 h the DAY-SEP kids were re-joined with their mothers and were allowed to suckle their dams during 30 min before afternoon milking. After milking, both goats and kids went back to their home pen, and stayed together during the night. The kids had free access to suckle both teats.

Finally, six kids, one male and five females, had full goat-kid contact and were kept together with their mothers in the home pen throughout 24 h (NON-SEP). These kids were only allowed to suckle one teat and the goats, therefore, had a specially designed bra suspended in harness to prevent the kids from suckling one teat.

The whole experimental period was 75 d, however, the kids were only weighed during 9 weeks.

https://doi.org/10.1017/S0022029921000789 Published online by Cambridge University Press

Milking procedures and milk analyses

The goats were machine milked twice daily at 7 : 30 in the morning and 15 : 30 in the afternoon, One goat at a time was milked in a milking parlour next door to the home pen. The goats were fed concentrate and carrots during milking. Both udder halves were milked separately with a specially designed 'separation-milker 8 l' bucket milking machine (provided by DeLaval international AB, Tumba, Sweden). Milk from each udder half was weighed separately. Milk samples were collected during 70 d and further details are described in the online Supplementary File. Briefly, samples of fresh milk were collected in 10 ml plastic tubes and heated in a water-bath to 40°C and analysed for fat, lactose and total protein by a mid-infrared spectroscopy method (Farm Milk Analyser Model 2001 previously calibrated for goat milk, Miris AB, Uppsala, Sweden). The casein concentration was determined by a rennet coagulation method and measured by the same mid-infrared spectroscopy method as above. Further explanations are described in the online Supplementary File. Compositional data were used to derive an estimated cheese yield, following the calculations described in Vacca *et al.* (2018).

Measurements of kids body weight and behaviour

Body weight of all kids was recorded once weekly from birth (week 0) until 9 weeks of age (Mettler Toledo, Stockholm, Sweden and Stathmos AB, Jönköping, Sweden). The kids were weighed only on a weekday: those born on a Saturday were weighed on a Friday and those born on a Sunday were weighed on a Monday. The weighing was performed in the afternoon just before DAY-SEP kids were reunited with their mothers.

At two weeks (range 12–16 d) and 2 months (range 59–69 d), instantaneous behavioural recordings of active and passive behaviour and if and to whom the kids had social contact, were made every 10^{th} minute. All kids were observed by direct observations from 7 : 00 h until 19 : 00 h by two observers and on both occasions the observations were performed during 3 d. The behaviours are defined and presented in online Supplementary Table S2.

Statistics

Data were examined using the repeated measurement ANOVA (mixed procedure) of the Statistical Analysis System (SAS Institute Inc. Cary, NC, USA, 2003). The statistical model included the effect of sample, system, gender and animal. Differences between genders are only presented when overall significances were found. Pairwise comparisons within treatment were tested for significance using differences in least square means (the DIFF option). Results are presented as means ± standard error of means (SEM), results from milk yield of individual goats are presented as a range (min −max). The significance level was set at $P \leq 0.05$.

Results

Body weight of kids

The kids' birthweights were 2880 ± 18 g, 2860 ± 21 g and 2730 ± 22 g in SEP, DAY-SEP and NON-SEP kids, respectively. At 9 weeks the kids weighed 14 000 ± 39 g (SEP), 14 700 ± 42 g (DAY-SEP) and 13 600 ± 33 g (NON-SEP). The mean daily weight gain was 180 ± 9 g/d (SEP), 190 ± 9 g/d (DAY-SEP) and 180 ± 8 g/d (NON-SEP). The weekly weight gain varied more in DAY-SEP kids compared to the other treatments but there was no difference in overall weight gain between treatments or between male and female kids (online Supplementary Figure S1).

Home pen behaviour and social position

Kids in all treatments were more active and spent less time resting at two months of age compared to two weeks of age ($P \leq 0.05$). There were no significant differences in total active or resting behaviour between treatments within age, see Table 1. The SEP kids spent more time being active with another kid at both two weeks and two months than NON-SEP kids. All groups were more active alone at 2 months compared to 2 weeks ($P \leq 0.05$). NON-SEP kids were more active with their mothers than DAY-SEP kids and this activity increased with age.

At two weeks the NON-SEP kids spent most time resting alone followed by DAY-SEP and SEP kids. In accordance, the SEP kids spent most time resting with another kid followed by DAY-SEP and NON-SEP kids (Table 1). When the mother was available, DAY-SEP kids spent 24% of their time with their mother at both ages. NON-SEP spent only 15% of available time with their mothers at 2 weeks of age and this increased to 28% at 2 months of age.

Milk yield and composition between treatments and udder halves within treatments

The milk yield varied greatly between animals; several goats yielded more than 3000 g/d (Table 2). Fat concentration and calculated cheese yield varied between animals compared to protein, casein and lactose concentration. The mean daily milk yield was higher in DAY-SEP goats compared with NON-SEP goats; 2420 g ± 119 g and 2149 ± 79 g kg, respectively ($P \leq 0.05$, Table 2). When comparing udder halves, there was no difference in either milk yield (1284 ± 77 g and 1081 ± 62 g) or fat concentration (Fig. 1) between left and right udder halves in DAY-SEP goats. In the NON-SEP goats milk yield was higher in the milked teats (1593 ± 57 g) compared to the suckled teats (510 ± 42 g, $P \leq 0.001$), as would be expected. When comparing milk fat concentration in NON-SEP goats, the milked gland had higher fat concentration at afternoon milking (5.7 ± 0.2%) than the suckled gland (4.6 ± 0.1%, $P \leq 0.05$, Fig. 1). This was reversed at the morning milking, with higher fat concentration now in the suckled gland ($P \leq 0.05$, Fig. 1). Both DAY-SEP and NON-SEP goats had a higher milk yield with lower fat concentration in morning milking compared to afternoon milking ($P \leq 0.05$). In total, there was no difference in milk fat concentration between the milked and suckled udder-halves.

The total protein concentration was 3.2 ± 0.04% for DAY-SEP and 3.1 ± 0.03% for NON-SEP goats and lactose concentration was 4.8 ± 0.1% for DAY-SEP and 4.7 ± 0.1% for NON-SEP goats. The casein concentration was 2.1% for both DAY-SEP and NON-SEP goats and the casein number (% of total protein) was 72% for both groups. The casein number was lower for both treatments on day 36 (68%) compared to day 75 (74%). There was no difference in casein concentration between udder halves.

Discussion

In this study, the goat-kid-bond was well established (Gubernick, 1981; Poindron *et al.*, 2003; Terrazas *et al.*, 2003) in all kids before they were divided into their respective system 5 d after parturition. According to earlier studies in goats, permanent separation goat kids was likely to lead to stressful reactions (Boivin and

https://doi.org/10.1017/S0022029921000789 Published online by Cambridge University Press

Table 1. Home pen behaviour at 2 weeks and 2 months of age

Treatments	SEP	DAY-SEP	NON-SEP	SEP	DAY-SEP	NON-SEP
Active (A)						
A. alone	17.1 ± 1.7^{b}	14.2 ± 1.7^{b}	11.7 ± 1.7^{b}	27.5 ± 1.7^{a}	24.2 ± 2.5^{a}	26.3 ± 2.9^{a}
A. kid	25.8 ± 1.7^{ab}	18.3 ± 2.1^{bc}	15.8 ± 2.1^{c}	31.2 ± 2.5^{a}	22.1 ± 2.1^{bc}	16.3 ± 2.5^{c}
A. mother	–	7.1 ± 2.5^{c}	11.7 ± 1.7	–	8.3 ± 2.1^{c}	15.8 ± 1.7^{a}
A. total	42.9 ± 2.5^{b}	41.2 ± 3.3^{b}	41.2 ± 2.5^{b}	59.2 ± 2.9^{a}	56.7 ± 4.2^{a}	61.2 ± 4.2^{a}
Resting (R)						
R. alone	5.4 ± 0.3^{c}	20.4 ± 4.2^{b}	34.2 ± 4.2^{a}	17.1 ± 2.5^{b}	12.1 ± 2.5^{bc}	14.2 ± 2.5^{b}
R. kid	38.8 ± 2.5^{a}	27.9 ± 3.8^{b}	15.8 ± 2.9^{c}	20.0 ± 2.5^{bc}	26.7 ± 2.9^{b}	9.2 ± 2.5^{c}
R. mother	–	2.9 ± 0.8^{b}	3.8 ± 1.7^{b}	–	1.7 ± 0.8^{b}	12.9 ± 3.3^{a}
R. total	43.8 ± 2.5^{ab}	51.7 ± 3.3^{a}	53.8 ± 2.5^{a}	37.1 ± 3.3^{b}	40.8 ± 4.2^{b}	36.3 ± 4.2^{b}

Resting and active behaviours alone, with mother or with other social companion in number of total observations (07.00–19.00 h) in three different treatments; SEP (separated from day 5), DAY-SEP (separated daytime between 7 : 30 and 15 : 00), and NON-SEP (kept with mother 24 h). Values are presented as means ± SEM. Different superscript letters between treatments and ages within a row differ at $P \leq 0.05$.

Table 2. Milk yield and composition in goats separated from their kids (DAY-SEP) or kept together with their kids for 24 h (NON-SEP)

Goat	M.Y (g)	M.Y range (g)	Fat (%)	Protein (%)	Lactose (%)	Casein (%)	Ch.Y (%)[a]
DAY-SEP							
1	3289 ± 217	2942–4342	4.8 ± 0.2	3.2 ± 0.0	4.9 ± 0.0	2.0 ± 0. 1	7.0
3	1943 ± 118	1562–2724	5.2 ± 0.2	3.3 ± 0.1	4.4 ± 0.1	2.0 ± 0.0	7.3
5	2488 ± 153	1792–3306	4.5 ± 0.3	2.7 ± 0.3	4.7 ± 0.1	2.0 ± 0.0	6.6
9	1854 ± 130	1360–2378	5.2 ± 0.2	3.0 ± 0.1	5.0 ± 0.1	2.1 ± 0.0	7.5
Total	2415 ± 119	1360–4343	4.9 ± 0.1	3.2 ± 0.0	4.8 ± 0.0	2.0 ± 0.0	7.0
NON-SEP							
2	1927 ± 107	1456–2402	4.7 ± 0.2	3.1 ± 0.1	5.0 ± 0.0	2.0 ± 0.0	6.8
4	2246 ± 131	1689–3140	4.3 ± 1.3	3.1 ± 0.1	4.7 ± 0.0	2.0 ± 0.1	6.4
7	2886 ± 85	2403–3242	4.2 ± 0.2	2.9 ± 0.0	4.8 ± 0.1	2.0 ± 0.0	6.3
8	2005 ± 125	1742–2416	4.6 ± 0.2	3.1 ± 0.0	4.8 ± 0.1	2.2 ± 0.0	7.0
10	2365 ± 156	1571–3454	4.1 ± 0.2	3.0 ± 0.0	4.5 ± 0.1	2.0 ± 0.0	6.2
12	1188 ± 81	972–1813	4.4 ± 0.2	3.2 ± 0.1	4.6 ± 0.0	2.5 ± 0.1	7.1
Total	2115 ± 81	972–3454	4.4 ± 0.1	3.1 ± 0.0	4.7 ± 0.0	2.1 ± 0.0	6.6

Values on milk yield (M Y) are presented as both means ± SEM and range. Values from milk composition are presented as means ± SEM.
[a]Cheese Yield (Ch Y) –solids was calculated according to (Vacca *et al.*, 2018).

Braadstad, 1996; Bergamasco *et al.*, 2005; Miranda de la Lama and Mattiello, 2010; Winblad von Walter *et al.*, 2010). Goats are usually considered to be hiders during the first weeks after parturition (O'Brien, 1984; Lickliter, 1984a, 1984b), and it has also been shown that this behaviour continues up to 6 weeks of age (McDougall, 1975). Field studies shows that nanny goats only visit and nurse their kids a few times per day early in lactation (O'Brien, 1984). In intensive management conditions, frequencies of nursing appear higher than those reported in feral goats (Delgadillo *et al.*, 1997), possibly because of confinement and reduced opportunity for the mother to move away. In the present study, kids that had full goat–kid contact showed more hiding behaviour at two weeks compared to the other treatments. In addition, the home pen behaviour showed that the more time the kids had access to their mother the more time they spent with them. At two weeks of age, kids with part time goat-kid contact spent 24% of the 4.5 h available time with her, while kids with full time contact spent 15.5%. SEP kids on the other hand spent more time close to another kid than kids in the other treatments did. After the hiding period, the kid initiates contact and seeks the mother when it wishes to suckle (Lickliter, 1984b). At that time it also starts to form social groups with other kids (Lickliter, 1987; O'Brien, 1988). In the present study, SEP kids were more active with other kids already at two weeks of age. At two months the kids with full time goat-kid contact spent 28% with their mothers and corresponding time for kids with partial goat-kid contact was 24% when the mother was available.

Rearing system did not affect the distribution of total time spent resting or being active at either age. However, when the kids were older they spent more time being active than when

https://doi.org/10.1017/S0022029921000789 Published online by Cambridge University Press

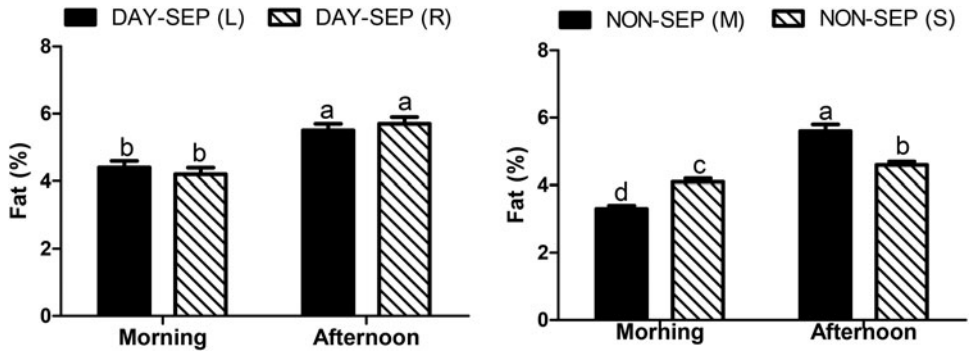

Fig. 1. Milk fat concentration from both udder halves in DAY-SEP left (L) and right (R) and from NON-SEP goats in the milked (M) and suckled (S) teats. The dams were machine milked twice daily (morning and afternoon) during 70 d. The DAY-SEP kids had free access to suckle both teats while NON-SEP kids only were allowed to suckle one teat as the other was covered with a bra suspended in harness to prevent suckling. The results are presented in means ± SEM. Different superscript letters within treatment differ significantly and the significance level was set at $P \leq 0.05$.

they were younger, which is in accordance with Lickliter (1987) who found that time spent lying declined after 4 weeks of age. We have previously reported results of isolation tests in the same kids at two weeks and two months of age and also an arena test at two months (Winblad *et al*., 2021). Artificially reared (SEP) deviated most from the other treatments in the isolation test at two weeks, by reducing their vocalization earlier and having a higher heart rate before and after the sound of a dog bark, and at two months, by having a higher heart rate throughout the test. On the other hand, DAY-SEP kids bleated comparatively more at two weeks, and showed a clear decrease in heart rate after the sound of a dog barking at two months. DAY-SEP-kids showed the strongest fear reaction in the arena test, performed at two months of age, showing increased escape behaviour before 'startle', and by a clear decrease in heart rate and greater passivity after the introduction of a novel object (Winblad *et al*., 2021).

An early separation between kids and their mothers is considered to be a stressful event, which often leads to reduced growth rates and weight loss (Miranda de la Lama and Mattiello, 2010). In the present study, the growth rate was high and similar overall in all treatments, indicating that the nutritional supply was not a limiting factor, regardless of access to the mother. However, DAY-SEP kids had larger variation in the weekly weight gain compared to the other kids. This might be caused by a higher stress since they were separated daily and might, therefore, have a more irregular suckling or eating pattern. However, they seemed to compensate the feed intake since they increased their bodyweight the following week. That SEP kids were fed goat milk from the herd could be one explanation for high growth rate in this treatment since Perez *et al*. (2001) demonstrated that kids reared on goat milk had higher average daily weight gain than kids fed with both goat and cow milk replacers. In contrast, two studies by Delgado-Pertinez et al. (2009a, 2009b) show that naturally reared kids of the Florida breed and Payoya breed had similar growth rate as artificially reared kids. Kids in the DAY-SEP system may have compensated their milk intake during the 16 h they spent together with their mothers. This is in agreement with Högberg *et al*. (2016) where daily separated kids compensated their milk intake equal even if they were separated for 8 h or 16 h.

The predetermined group division led to a skewed gender distribution between treatments, as it resulted in primarily keeping the female kids with their mothers, therefore, gender effects are not presented or discussed.

Our study confirms that it is possible to maintain marketable milk yield during 70 d in Swedish dairy goats kept together with one kid. The daily milk yield in Swedish dairy herds has been estimated to be 2.8 L per day (Brandt, 2009). The goats in this study had lower milk yield in comparison (2.4 kg in DAY-SEP and 2.1 kg/d in NON-SEP). The theoretical cheese yield measured as percentage solids (Vacca *et al*., 2018) was higher than commonly seen in Swedish goats where there is a need for about 10 kg milk to produce 1 kg of semi-hard cheese. The calculated corresponding value for DAY-SEP was 7.1 kg and from NON-SEP 7.5 kg milk, respectively. However, the goats in this study produced more milk in comparison to other goat breeds kept together with their kids. For example, the daily production of marketable milk for Payoya dairy goats was 2.0 l during the suckling period and 2.1 l after weaning (Delgado-Pertinez *et al*., 2009b). Florida dairy goats kept with their kids yielded 1 l marketable milk (Delgado-Pertinez *et al*., 2009a). This suggests that suckling can stimulate milk synthesis and thereby maintain milk for human consumption, which is somewhat contrary to common belief, a belief that constitutes motivation for early separation in the dairy industry (Balasse, 2003; Delgado-Pertínez *et al*., 2009a, 2009b). We have recently shown that keeping goat and kid together results in better udder emptying and higher fat concentration, resulting in a maintained curd yield (Högberg *et al*., 2016). Even when the dams were kept together with one kid for 24 h, some individuals yielded 3–4 kg milk daily, containing a fat concentration of 4–5%. That is unusual in the Swedish breed since they normally have a fat concentration around 3.0–3.4% (unpublished results: we did not include mothers kept apart from their kids in the current analyses). One could hypothesize that more frequent mammary gland stimulation or emptying could increase local synthesis of milk fat within the mammary gland, although we are not aware of any specific evidence on this point, and our own observation of reversed fat content differential at morning and afternoon milking demonstrates the complexity of this relationship.

Delgado-Pertínez *et al*. (2009a) demonstrated that dams kept with their kids for 18–20 h daily, had higher milk production during the entire lactation (210 d) than dams that were only milked (no kids). In contrast, Peris *et al*. (1997) found no difference in milk production between naturally suckled dams (separated from their kids for 6 h in daytime) and dams milked only. In the present study, the individual variation in milk yield was high. Therefore, an alternative to daily separations is to only

https://doi.org/10.1017/S0022029921000789 Published online by Cambridge University Press

choose high producing goats and let them go together with their kids 24 h. The goats and kids used in this study were probably affected by the daily separation even though they were habituated to the procedure. Both dams and kids seem to be restless and they bleated, especially when the door between the dams' and kids' rooms was opened (personal observations). Keeping them together for 24 h constitutes good conditions for high milk production, improved animal welfare and reduced workload for the farmer. Another factor that might be important when goats are reared together with their kids is when the adaptation to milking occurs. The successful results in this study (both high fat content and high milk yield) could also be due to the goats being conditioned to machine milking in an early stage of lactation. Högberg (2016) showed that when adaption to machine milking occurs in a later stage of lactation, the milk ejection reflex became inhibited and only cisternal milk was available for milking (Högberg *et al.*, 2014). This might not always be the case but may be an important factor when keeping dams and kids together in the dairy production.

Another scenario that might occur when adoption to milking occurs later can result in reduced milk synthesis in one of the udder halves. High yielding dams often produce more milk than one kid can empty and the kids might therefore prefer to suckle one teat only (unpublished results). Less frequent udder emptying regresses milk yield and production (Knight and Wilde, 1993) and the unsuckled teat will finally get dry.

Contradictory to Stelwagen (2001), our results showed that there was no difference in milk fat concentration between the milked and suckled teat in total, even if the milk volume was higher in the milked teat compared with the suckled teat. This indicates that the effects seen on milk synthesis were rather centrally regulated by hormones (oxytocin, prolactin) than due to local mechanisms in the udder half. Removal of milk from the mammary gland is critical for eliciting changes in local factors that are limiting to milk production. In addition, local regulatory mechanisms influence the response of the mammary gland to hormones in the circulation (Wall and McFadden, 2012).

Comparing the milk yield and composition in teats that were either milked or suckled, the milk yield was, as expected, higher in the milked teat. However, there were great individual differences between animals in fat concentration. An interesting observation was that the fat concentration was often higher in the teat with higher amounts of milk. This was seen repeatedly in both NON-SEP and DAY-SEP goats.

In total (both morning and afternoon milkings), there was no difference in milk fat concentration between the suckled and milked teats or in the left or right teats. This might be explained by the fact that the Swedish landrace goats are able to store large amount of fat rich alveolar milk in their large cisterns once ejected by suckling.

The results showed that the casein number (% of total protein) was lower on day 36 compared with later stages in both DAY-SEP and NON-SEP goats. This is in agreement with earlier findings that have shown that the casein number is lower in the beginning of lactation (day 14, 64%) compared to later stages (74%; Högberg, 2016). The low casein number in the beginning of lactation can be explained from a physiological perspective by the casein and whey levels changing as lactation progresses to meet the nutritional needs of the offspring. The whey fraction consists of β-lactoglobulin, α-lactalbumin, serum-albumins and immunoglobulins (Walstra *et al.*, 1999), of which the latter play a very important role in immunological defence for the offspring. When the protein consists of a high whey fraction (low casein) in the beginning of lactation it might also explain why it is more complicated to produce cheese during that time. This problem is commonly known among goat cheese producers in Sweden.

In conclusion, kids managed either with or without access to their mothers had similar growth rates, but an altered behaviour, with less hiding behaviour, was seen in early separated kids. Kids that had access to their mothers spent considerable time with them which shows that if they can choose, they choose to be with their mothers. This most likely affected the welfare of both the kids and the goats. The results also show that it is possible to maintain a high milk yield with one kid present and that the milk composition is positively affected by keeping goats and kids together.

Supplementary material. The supplementary material for this article can be found at https://doi.org/10.1017/S0022029921000789.

Acknowledgments. We thank all goats, kids and Mrs Åsa Eriksson for technical assistance and taking good care of the animals and Emma Ternman for assistance and help of designing the bra. This work was supported by the Swedish Medical Research Council (project no 3392), the Swedish Council for Agricultural and Forestry Research and the Swedish Farmers' Foundation for Agricultural Research.

Conflict of interest. No conflict of interest to report.

References

Balasse M (2003) Keeping the young alive to stimulate milk production? Differences between cattle and small stock. *Anthropozoologica* **37**, 3–10.

Bergamasco L, Macchi E, Facello C, Badino P, Odore R, Pagliasso S, Bellino C, Osella MC and Re G (2005) Effects of brief maternal separation in kids on neurohormonal and electroencephalographic parameters. *Applied Animal Behaviour Science* **93**, 39–52.

Boivin X and Braadstad BO (1996) Effects of handling during temporary isolation after early weaning on goat kids' later response to humans. *Applied Animal Behaviour Science* **48**, 61–71.

Brandt L (2009) Djurhållning och hälsoproblem i Svenska mjölkgetbesättningar- sett ur ett djurägarperspektiv. Examensarbete ISSN 1652–8697.

Bruckmaier RM (2005) Normal and disturbed milk ejection in dairy cows. *Domestic Animal Endocrinology* **29**, 268–273.

Clark S and Sherbon JW (2000) Alphas1-casein, milk composition and coagulation properties of goat milk. *Small Ruminant Research* **38**, 123–134.

Delgadillo JA, Malpaux B and Chemineau P (1997) La reproduction des caprine dans les zones tropicales et subtropicales. *INRA Productions Animales* **10**, 33–41.

Delgado-Pertínez M, Guzmán-Guerrero JL, Caravaca FP, Castel JM, Ruiz FA, González-Redondo P and Alcalde MJ (2009a) Effect of artificial *vs.* Natural rearing on milk yield, kid growth and cost in Payoya autochthonous dairy goats. *Small Ruminant Research* **84**, 108–115.

Delgado-Pertínez M, Guzmán-Guerrero JL, Mena Y, Castel JM, González-Redondo P and Caravaca FP (2009b) Influence of kid rearing treatments on milk yield, kid growth and cost of Florida dairy goats. *Small Ruminant Research* **81**, 105–111.

Diaz E, Analla M, Munoz-Serrano A, Alonso-Moraga A and Serradilla JM (1999) Variation of milk yield and contents of total casein and casein fractions in Murciano-Granadina goats. *Small Ruminant Research* **34**, 141–147.

FAO (2014) FAOSTAT. Available at http://faostat.fao.org/default.aspx.

Gubernick DJ (1981) Mechanisms of maternal "labelling" in goats. *Animal Behaviour* **29**, 305–306.

Hernandez H, Delgadillo JA, Flores JA, Rodríguez AD, Serafín N, Kann G, Marnet PG and Poindron P (2007) Effects of restricted nursing on milk production and collection, kid growth and plasma prolactin and growth hormone concentrations in dairy goats. *Animal: An International Journal of Animal Bioscience* **1**, 233–240.

Högberg M (2011) On farm analyses of milk composition in Swedish landrace goats by a mid-infrared spectroscopy method, MIRIS. Available at http://stud.epsilon.slu.se/3291/.

Högberg M (2016) Keeping goats and kids together – Focus on milk ejection, milk composition curd yield and animal welfare. Available at https://pub.epsilon.slu.se/13332/1/hogbergm160502.pdf.

Högberg M, Olsson K and Dahlborn K (2014) Can vasopressin induce milk ejection in the dairy goat? *Small Ruminant Research* **121**, 111–115.

Högberg M, Dahlborn K, Hydbring-Sandberg E, Hartmann E and Andrén A (2016) Milk processing quality of suckled/milked goats: effects of milk accumulation interval and milking regime. *Journal of Dairy Research* **83**, 173–179.

Knight CH and Wilde CJ (1993) Mammary cell changes during pregnancy and lactation. *Livestock Production Science* **35**, 3–19.

Knight TV, Atkinson DS, Haak NA, Palmer CR and Rowland KH (1993) Effects of suckling regime on lamb growth rates and milk yields of Dorset ewes. *New Zealand Journal of Agricultural Research* **36**, 215–222.

Lickliter RE (1984a) Hiding behaviour in domestic goat kids. *Applied Animal Behaviour Science* **12**, 245–251.

Lickliter RE (1984b) Mother-infant spatial relationships in domestic goats. *Applied Animal Behaviour Science* **13**, 93–100.

Lickliter RE (1987) Activity patterns and companion preferences of domestic goat kids. *Applied Animal Behaviour* **19**, 137–145.

Marnet PG and Komara M (2008) Management treatments with extended milking intervals in ruminants: regulation and production and quality of milk. *Journal of Animal Science* **86**, 47–56.

Marnet PG and McKusick BC (2001) Regulation of milk ejection and milkability in small ruminants. *Livestock Production Science* **70**, 125–133.

Marnet PG and Negrão JO (2000) The effect of a mixed-management system on the release of oxytocin, prolactin, and cortisol in ewes during suckling and machine milking. *Reproductive, Nutrition Development* **40**, 271–281.

McDaugall P (1975) The feral goats of Kielderhead Moor. *Journal of Zoology* **176**, 215–246.

McKusick BC, Thomas DL, Berger YM and Marnet PG (2001) Effect of weaning system on commercial milk production and lamb growth of east Friesian dairy sheep. *Journal of Dairy Science* **84**, 1660–1668.

McKusick BC, Thomas DL, Romero JE and Marnet PG (2002) Effect of weaning system on milk composition and distribution of milk fat within the udder of east Friesian dairy ewes. *Journal of Dairy Science* **85**, 2521–2528.

Miranda-de la Lama GC and Mattiello S (2010) The importance of social behaviour for goat welfare in livestock farming. *Small Ruminant Research* **90**, 1–10.

Newberry RC and Swanson JC (2008) Implications of breaking mother–young social bonds. *Applied Animal Behaviour Science* **110**, 3–23.

O'Brien PH (1984) Leavers and stayers: maternal postpartum strategies in feral goats. *Applied Animal Behaviour Science* **12**, 233–243.

O'Brien PH (1988) Feral goat social organisation: a review and comparative analysis. *Applied Animal Behaviour Science* **21**, 209–221.

Olsson K and Högberg M (2008) Plasma vasopressin and oxytocin concentrations increase simultaneously during suckling in goats. *Journal of Dairy Research* **75**, 1–5.

Perez P, Maino M, Morales MS and Soto A (2001) Effect of goat milk and milk substitutes and sex on productive parameters and carcass composition of Creole kids. *Small Ruminant Research* **42**, 87–94.

Peris S, Caja G, Such X, Casals R, Ferret A and Torre C (1997) Influence of kid rearing treatments on milk composition and yield of Murciano-Granadina dairy goat. *Journal of Dairy Science* **80**, 3249–3255.

Poindron P, Gilling G, Hernndez H, Serafin N and Terrazaz A (2003) Early recognition of newborn goat kids by their mother: I. Nonolfactory discrimination. *Developmental Psychobiology* **43**, 82–89.

Rassu SPG, Nudda A, Carzedda C, Battacone G, Bencini R and Pulina G (2015) A partial suckling regime increases milk production in Sarda dairy sheep without affecting meat quality of lambs. *Small Ruminant Research* **125**, 15–20.

Sirovnik J, Barth K, de Oliveira D, Ferneborg S, Haskell M, Hillmann E, Bak Jensen M, Mejdell C, Napolitano F, Vaarst M, Verwer C, Waiblinger S, Zipp K and Føske Johnsen J (2020) Methodological terminology and definitions for research and discussion of cow-calf contact systems. *Journal of Dairy Research* **87**, 108–114.

Soryal K, Beyene FA, Zeng S, Bah B and Tesfai K (2005) Effect of goat breed and milk composition on yield, sensory quality, fatty acid concentration of soft cheese during lactation. *Small Ruminant Research* **58**, 275–281.

Stelwagen K (2001) Effect of milking frequency on mammary functioning and shape of the lactation curve. *Journal of Dairy Science* **84**(suppl.), E204–E211.

Terrazas A, Serafin N, Hernández H, Nowak R and Poindron P (2003) Early recognition of newborn goat kids by their mother: II. Auditory recognition and evidence of an individual acoustic signature in the neonate. *Developmental Psychobiology* **43**, 311–320.

Vacca GM, Stocco G, Dettori ML, Summer A, Cipolat-Gotet C, Bittante G and Pazzola M (2018) Cheese yield, cheesemaking efficiency and daily production of 6 breeds of goats. *Journal of Dairy Science* **101**, 7817–7832.

Wall EH and McFadden TB (2012) A local affair: how the mammary gland adapts to changes in milking frequency. *Journal of Animal Science* **90**, 1695–1707.

Walstra P, Geurts TJ, Noomen A, Jellema A and van Boekel MAJS (1999) *Dairy Technology: Principles of Milk Properties and Processes*. Marcel Dekker, New York.

Wilde CJ, Henderson AJ, Knight CH, Blatchford DR, Faulkner A and Vernon RJ (1987) Effects of long-term thrice-daily milking on mammary enzyme activity, cell population and milk yield. *Journal of Animal Science* **64**, 533–539.

Wilde CJ, Addey CV, Boddy LM and Peaker M (1995) Autocrine regulation of milk secretion by a protein in milk. *Biochemical Journal* **305**, 51–58. [PubMed: 7826353].

Winblad von Walter L, Lidfors L, Madej A, Dahlborn K and Hydbring-Sandberg E (2010) Cardiovascular, endocrine and behavioural responses to suckling and permanent separation in goats. *Acta Veterinaria Scandinavica* **52**, 51–59.

Winblad von Walter L, Forkman B, Högberg M and Hydbring-Sandberg E (2021) The effect of mother goat presence during rearing on kids' response to isolation and to an arena test. *Animals* **11**, 2.