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Drying-off practices on Swiss dairy farms: Status quo and adoption potential of integrating incomplete milking

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ABSTRACT

Drying-off practices to reduce milk production before dry-off are gaining attention because high milk yields at dry-off are becoming more common and increase the risk to cow health and welfare during the dry period. Incomplete milking for the last days before dry-off is one approach for reducing milk production. We conducted an online survey to determine the currently used drying-off practices on Swiss dairy farms and to identify the adoption potential of integrating incomplete milking before dry-off. In March 2021, the online survey was sent to a representative sample of 1,974 Swiss dairy farmers. A total of 518 completed questionnaires were analyzed. The mean number of dairy cows per farm was 39 (range: 11–140 cows). Thirty-five percent of cows produced considerable quantities of milk (>15 kg/d) at dry-off, and milk yield at dry-off increased with increasing annual milk yield. Abrupt dry-off was applied on 45% of the farms. The participants reported observing behavioral changes of cows such as increased vocalizations and decreased lying time associated with dry-off. Selective dry cow therapy was applied on 74% of the farms, and 44% of the participants indicated the use of antibiotics at dry-off as being "rather often," "often," or "always." Correlation analysis revealed that with increasing annual milk yields, the frequency of observed behavioral changes and antibiotic use at dry-off increased as well. Therefore, drying-off approaches that reduce milk production while supporting cow welfare are needed. We found that farmers showed an interest in testing the presented drying-off approach of incomplete milking. In addition, the farmers indicated that they would be more willing to test incomplete milking before dry-off if it became available for automated use in milking parlors or robots. Uncertainties regarding udder health appeared to be the main barrier for the adoption potential of this approach.

Key words: gradual dry-off, partial milking, reduced milk harvest, farmer perception

INTRODUCTION

The transition from a lactating to a nonlactating state during dry-off is a vulnerable period for dairy cows and marks a stage of increased susceptibility to IMI (Bradley and Green, 2004). With the increased milk production potential of the modern dairy cow (Barkema et al., 2015), drying-off has become more challenging. High milk yield at dry-off was found to increase the risk for developing milk leakage (Bertulat et al., 2013; Gott et al., 2016; De Prado-Taranilla et al., 2020) and IMI during the dry period (Rajala-Schultz et al., 2005; Newman et al., 2010) because the keratin plug formation in the teat canal was impaired (Dingwell et al., 2004). In addition, high milk yield at dry-off was associated with increased udder pressure and stress levels after dry-off, and abrupt cessation of milking may cause discomfort and pain (Bertulat et al., 2013; Silanikove et al., 2013; Zobel et al., 2015). Therefore, reducing milk production before dry-off and accelerating mammary gland involution is beneficial for cow health and welfare.

Reduced milk production before dry-off can be achieved by reducing milking frequency or nutrient intake or by combining both practices (Tucker et al., 2009; Larsen et al., 2021). Incomplete milking might be an alternative approach for reducing milk production of dairy cows by gradually increasing early manual cluster detachment (Penry et al., 2017; Albaaj et al., 2018; Kuehnl et al., 2019). Application of incomplete milking during the first 5 DIM enabled a reduction in metabolic stress for cows by limiting milk production (Carbonneau et al., 2012; Morin et al., 2018). Martin et al. (2020) studied the effects of incomplete milking when applied about 10 d before dry-off. For this pur-

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pose, they developed a software module that removed the milking cluster automatically at a defined targeted setting, before reaching the conventional cluster take-off level. The step-down program reduced udder emptying daily. On average, milk production was reduced by 35% before cessation of milking. The stimulation of mammary gland involution has been suggested to be due to a measurable increase in the acute-phase protein haptoglobin in foremilk samples (Martin et al., 2020). Although the approach of incomplete milking is still in development, it could facilitate drying-off by automatically controlling incomplete milking.

In general, several drying-off practices exist, including ones that are applied either abruptly or gradually. Abrupt dry-off involves a sudden stop to milking, whereas gradual drying-off practices aim to reduce milk production before dry-off. Gradual dry-off is achieved by reducing milking frequency or nutrient intake or by using both practices in combination. Antibiotic dry cow therapy (**DCT**), teat sealants, and changes in cows' housing are also applied for drying-off. Furthermore, drying-off can be supported by pharmaceuticals such as dopamine agonists that inhibit prolactin release (Lacasse et al., 2019), casein hydrolysates (Ponchon et al., 2014), chitosan hydrogels (Lanctôt et al., 2017), and acidogenic mineral boluses that induce transient metabolic acidogenesis (Maynou et al., 2018). However, these compounds are not commonly commercially available.

Prudent administration of antibiotics and consideration of animal welfare are current topics of public interest. Although antibiotic treatment plays an important role in maintaining the health and well-being of sick animals, reduced and more prudent administration of antibiotics is needed because antimicrobial resistance has become a global public health concern (European Union, 2018). Therefore, since the law changed in 2016, antibiotics may no longer be dispensed for prophylactic use in Switzerland (Veterinary Medicines Ordinance, 2016). At the same time, a trend exists toward a decrease in the number of farms and an increase in farm size (Federal Statistical Office, 2020). In contrast, consumers prefer small-scale farms because they perceive that natural housing conditions are essential for animal welfare and they believe such conditions are only provided on small-scale farms (Krystallis et al., 2009; Spooner et al., 2014; Robbins et al., 2016). Therefore, with the intensification of the dairy industry, animal welfare is increasingly in the public focus and has become an important issue for consumers (Spooner et al., 2014; Barkema et al., 2015).

Despite research efforts to develop alternative drying-off practices and to improve those now in use (Dancy et al., 2019; Martin et al., 2020; Larsen et al., 2021), knowledge about the practices currently applied on dairy farms is scarce. In addition, knowledge about farmers' adoption potential to implement novel drying-off practices is lacking. Farmers' adoption of management practices is influenced by their individual circumstances such as farm characteristics and by the perceived effectiveness and feasibility of recommended practices (Ritter et al., 2017). Therefore, it appears appropriate to inform farmers early about new developments in drying-off approaches and to solicit their opinion on these approaches. Our study focused on 2 aims: (1) determining the status quo of implemented drying-off practices on Swiss dairy farms, and (2) identifying the adoption potential of integrating incomplete milking during drying-off.

MATERIALS AND METHODS

Sample

We selected a representative sample of Swiss dairy farms stratified by the herd size of the farms and the production zone (valley, hill, mountain) in which the farm is located. To exclude hobby farmers, we applied a cutoff point of ≤10 dairy cows. For the survey process, only farmers with an email address as well as a postal address were included in the survey. Furthermore, the sample focused on the parts of Switzerland where German and French are spoken. For the sampling baseline, the Swiss Farm Structure Survey and the resulting agricultural policy information system data set of 2019 were used (Federal Statistical Office, 2016). Farms drawn for the sample were assigned an identification code to ensure the anonymity of the survey. The cover letter was sent by regular mail and was addressed to the farm managers. Three weeks after the postal cover letter was mailed, a reminder to participate in the survey was sent to the selected farms by email. The data collection took place in March and April 2021. Following institutional (Agroscope, 2019) and psychological (American Psychological Association, 2002) ethical guidelines, participants provided informed, written consent before starting with the anonymized questionnaire.

We contacted 10% of Swiss dairy farmers, representing 1,974 Swiss dairy farms, to obtain a representative sample (Federal Office for Agriculture, 2020). Overall, 527 participants completed the online survey, resulting in a response rate of 27%. After data cleaning, 518 questionnaires were considered. The farm managers were on average 46 yr old (range: 21–69 yr), 500 were male, and almost 80% filled in the German version of the questionnaire. Overall, farming was the main occupation of 500 participants, and 77 farms were organic farms.

Questionnaire

A comprehensive questionnaire was developed for the online survey. The questionnaire was developed in German and translated to French by a professional translator. The online survey was conducted using Questback's Enterprise Feedback Suite survey software (Questback), and the median completion time was 35 min. Participants were able to access the online survey by using the provided link or QR code. The questionnaire was pretested with 6 farmers with regard to its comprehensibility and length, and we subsequently revised the questionnaire according to their feedback.

The questionnaire was organized in 3 parts. In the first part, farmers were asked to provide general information about their farms, such as farm size, annual milk production, and the type of milking system in use. The second part focused on the drying-off practices that were in use on the farms. To determine the level of milk production at the time of dry-off, participants were shown 7 sliders labeled with different milk production levels per cow (from <5 to >30 kg/d). Participants were then asked to indicate on each slider the percentages of cows (from 0 to 100%) with that milk production level that were drying off. The second part also addressed topics such as the use of antibiotics and teat sealers at dry-off and cow welfare. Participants were asked to use a 6-point scale (1 = never; 2 = very rarely; 3 = rather rarely; 4 = rather often; 5 = very often; and 6 = always) to indicate how frequently they applied antibiotics and teat sealers at dry-off and how frequently they observed behavioral changes in their cows associated with dry-off. Behavioral changes were assessed according to the frequency of observed milk leakage, agitation, reduced feed intake, increased vocalization, and decreased lying time. The third part of the survey presented a gradual drying-off approach based on incomplete milking before dry-off. For this, we provided the participants with 2 alternative descriptions of the approach, using phrasing based on the study by Martin et al. (2020). After reading the 2 descriptions, participants were asked to write down their spontaneous reaction to each. The first description explained how the approach is performed, and the second stated that the current state of research showed that applying this approach had no negative impact on udder health. Participants were asked to write only the first word that came to their mind. Then they were asked to rate that word on a scale from 1 (very negative) to 100 (very positive). Finally, participants were asked about their willingness to test this drying-off approach, once generally with regard to whether the approach would be accepted, and once specifically if the approach were available for automated use in milking parlors or robots. A 6-point scale was used to indicate the test willingness: 1 = no, definitely not; 2 = no, very likely not; 3 = no, rather likely not; 4 = yes, rather likely; 5 = yes, very likely; and 6 = yes, definitely.

Statistical Analyses

Data were checked for consistency and completeness. Sample sizes differed between n = 471 and n = 518 owing to missing values for individual items. Statistical Package for the Social Science Version 26 (IBM) was used for quantitative data analysis. Qualitative data analysis was performed using Excel 2016 (Microsoft). For the analysis of the status quo, descriptive statistics were used. To investigate relationships between the variables (Table 1), Spearman's rank correlation (coefficient: rho) was used because the assumptions for parametric testing were not fulfilled. We also conducted Spearman's rank correlation to show relationships between the willingness to test the presented drying-off approach and the characteristics of the farmers and the farms. For the interpretation of rho values, criteria defined by Cohen (1988) were used as follows: weak correlation = 0.1, moderate correlation = 0.3, and strong correlation = 0.5.

Finally, to explore spontaneous associations regarding the presented drying-off approach, participants' responses were grouped into categories based on their meaning and word family affiliation. This grouping resulted in 18 categories that were named accordingly. We used a paired-samples *t*-test to check whether the ratings of the words associated with the 2 alternative descriptions of the incomplete milking approach differed significantly. The significance threshold was set at $P \leq 0.05$.

RESULTS

Farm Characteristics

For the 518 participating farms, the mean number of dairy cows, including lactating and dry cows, was 39 (range: 11–140 cows). In terms of housing, 304 farms kept their cows in loose housing systems, 197 kept them in tie stall barns, and 17 had both husbandry systems. The mean annual milk yield per cow for about a quarter of the farms was categorized as follows: 6,000–6,999 kg, 7,000–7,999 kg, or 8,000–8,999 kg. Of the remaining farms, 11.8% (61/518) reported less than 6,000 kg milk yield per cow per year, and 14.9% (77/518) reported more than 9,000 kg milk yield per cow per year. On

Table 1. Spearman rho correlation coefficients for mean annual milk yield per cow (kg), number of dairy cows, dry period length (d), milking system, use of antibiotics at dry-off, and observations such as milk leakage and behavioral changes associated with dry-off[1]

	1	2	3	4	5	6a–6e				
						Observations associated with dry-off				
Number	Annual milk yield[2]	Number of dairy cows[2]	Dry period length[3]	Milking system[4]	Antibiotics at dry-off[5]	Milk leakage[6]	Agitation[3]	↓ Feed intake[7]	↑ Vocalization[6]	↓ Lying time[3]
1	—									
2	0.52***	—								
3	−0.22***	−0.13**	—							
4	0.42***	0.61***	−0.12**	—						
5	0.21***	0.09*	NS	NS	—					
6a	NS	NS	NS	NS	0.12**	—				
6b	0.24***	0.12**	−0.10*	0.10*	0.10*	0.38***	—			
6c	0.15**	NS	NS	NS	NS	0.29***	0.60***	—		
6d	0.18***	NS	NS	NS	NS	0.38***	0.62***	0.56***	—	
6e	0.11*	NS	NS	NS	NS	0.36***	0.59***	0.59***	0.63***	—

[1]Sample sizes differed owing to missing values. Variables were coded as follows. Mean annual milk yield per cow: 1 = less than 6,000 kg; 2 = 6,000–6,999 kg; 3 = 7,000–7,999 kg; 4 = 8,000–8,999 kg; and 5 = more than 9,000 kg. Number of dairy cows: 1 = 8–25 cows; 2 = 26–50 cows; 3 = 51–75 cows; 4 = 76–100 cows; and 5 = 101–140 cows. Dry period length: 1 = less than 40 d; 2 = 40–49 d; 3 = 50–59 d; 4 = 60–69 d; 5 = 70–79 d; and 6 = 80 d or longer. Milking system according to degree of automation: 1 = bucket; 2 = pipeline; 3 = milking parlor; and 4 = automatic milking system. Antibiotic use at dry-off and observations such as milk leakage and behavioral changes associated with dry-off: 1 = never; 2 = very rarely; 3 = rather rarely; 4 = rather often; 5 = very often; and 6 = always.

[2]n = 518.

[3]n = 516.

[4]n = 508.

[5]n = 517.

[6]n = 515.

[7]n = 513.

$^*P < 0.05$; $^{**}P < 0.01$; $^{***}P < 0.001$.

85.7% (444/518) of the farms, the mean annual bulk milk SCC was less than 150,000 cells/mL. Regarding the milking system used, 44.7% (227/508) of the farms used a milking parlor, 34.3% (174/508) used a pipeline, 11.6% (59/508) used an automatic milking system (**AMS**), and 9.4% (48/508) used a bucket milking system. Figure 1 shows the relation between mean annual milk yields per cow and the milking system used. With increasing annual milk yields, we found that farms used AMS and parlors more frequently than bucket and pipeline milking systems (Figure 1 and Table 1). The annual milk yields were significantly positively correlated with the number of dairy cows (Table 1). Consequently, as the number of dairy cows increased, the milking system used on the farm had a higher level of automation, meaning AMS and parlors were more common than bucket and pipeline milking systems (Table 1).

Drying-off Practices

The mean length of the dry period in our sample was 57 d (range: 7–100 d). Farmers in our survey indicated that they select the date for dry-off based on various aspects, with the calculated calving date being the most important factor. The level of milk production at the end of lactation and udder health also play roles in determining the dry-off date. The length of the dry period was significantly negatively correlated with the annual milk yield per cow (Table 1).

The majority of farms (55.0%, 285/518) performed a gradual dry-off, whereas on 45.0% (233/518) of farms, cows were dried off abruptly without any previous preparation. When cows were gradually dried off, the combination of reduced milking frequency and reduced nutrient intake was applied most (29.2%, 151/518). Reduced milking frequency or adjusted feed ration alone was described by 12.5% (65/518) and 13.3% (69/518) of the farmers, respectively. About 1% (5/518) of farmers also limited cows' water access. Cows' housing was changed on 23.6% (122/518) of the farms before the beginning of the dry period.

Regarding the use of antibiotics, 73.7% (382/518) of farms applied selective DCT and 12.2% (63/518) used blanket DCT, and 14.1% (73/518) did not use antibiotic DCT at all. Selective DCT was the most common treatment on conventional farms (76.0%, 335/441) and on organic farms (61.0%, 47/77). Conventional farms applied blanket DCT (13.6%, 60/441) more frequently than no DCT (10.4%, 46/441), whereas organic farms applied no DCT (35.1%, 27/77) more frequently than blanket DCT (3.9%, 3/77). The lower the annual milk

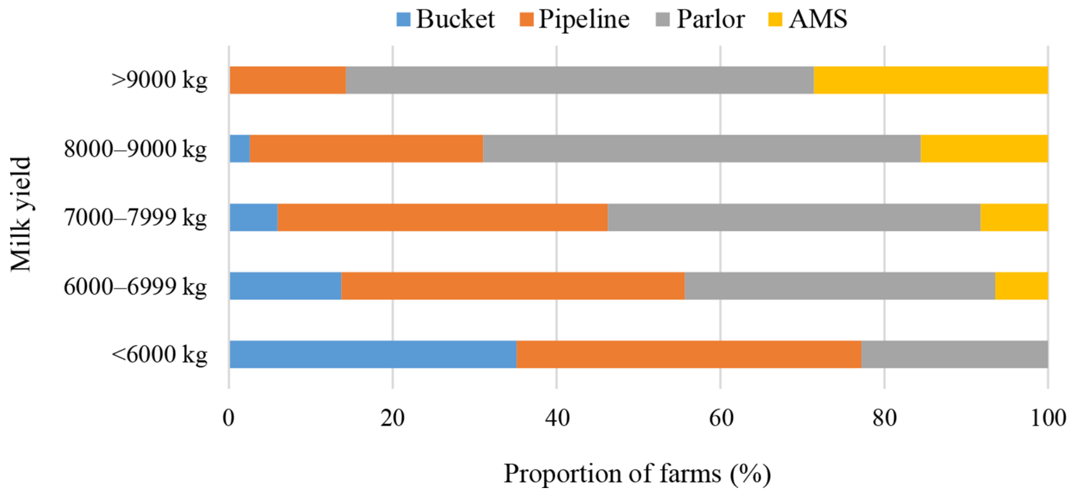

Figure 1. Annual milk yield per cow in relation to the milking system (n = 508). The milking system is sorted from left, little automated (bucket) to right, fully automated (automatic milking system, AMS).

yields, the less frequently antibiotic DCT was applied (Figure 2).

Need for Alternative Drying-off Practices

Figure 3 shows that 35.1% (178/508) of cows were dried off while milk production was still above 15 kg/d. The annual milk yield per cow influenced the amount of milk produced at dry-off (Figure 4). High-yielding cows with a higher milk production level per year had higher milk yields at dry-off.

Participants reported changes in their cows that potentially indicated compromised udder health and cow welfare. About one quarter of the participants indicated that they rather often to always observed milk leakage, reduced feed intake, and increased vocalization of their cows associated with dry-off (Figure 5). Following up on this finding, Table 1 shows that annual milk yields correlated significantly positively with the frequency with which behavioral changes such as increased vocalization and decreased lying time associated with dry-off were observed.

Our survey also shows that 43.9% (227/517) of participants reported using antibiotics at dry-off rather often to always. Correlation analysis confirmed a positive relationship between annual milk yields and the use of antibiotics at dry-off (Table 1). The combination of antibiotics and internal teat sealant was used

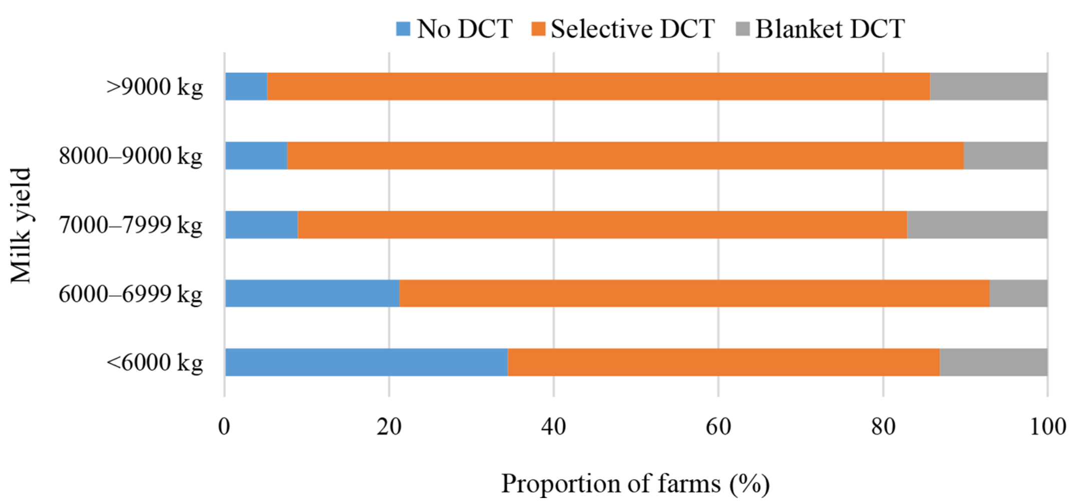

Figure 2. Annual milk yield per cow in relation to antibiotic dry cow therapy (DCT; n = 518). From the left to the right: no use of antibiotic DCT at all; selective DCT; blanket DCT.

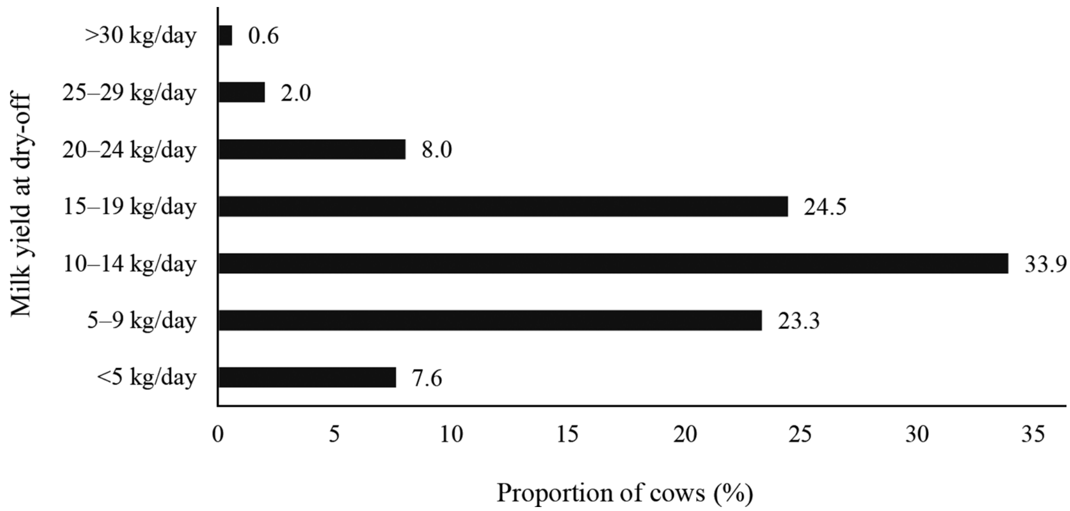

Figure 3. Milk yields at dry-off (n = 508).

rather often to always on 5.6% (27/479) of farms. Teat sealants alone, without concomitant use of antibiotics, were applied rather often to always as follows: internal on 42.6% (213/500) of farms and external on 4.2% (20/471) of farms.

Perception of Presented Drying-off Approach

Table 2 shows the spontaneous responses of the participants to the presented drying-off approach of incomplete milking. After the first description of the presented drying-off approach, spontaneous reactions were dominated mainly by uncertainties about udder health and feasibility. According to the second description, which indicated that recent research showed the concomitant approach had no negative impact on udder health, spontaneous reactions were dominated by interest and positive evaluations by up to 25.5% and 15.1% of participants, respectively. Uncertainties regarding udder health decreased from 13.3% to 5.0%. In addition, some participants wanted to know whether it is legal to deliver milk from cows that are milked incompletely. Thirty participants stated that they already knew about this drying-off approach, for example, referring to it as "grandfather's practice" or even using it manually.

A *t*-test for paired samples showed that the second description about the nonimpairment of udder health by incomplete milking significantly positively influenced the perception of this approach ($t_{517} = -9.22$;

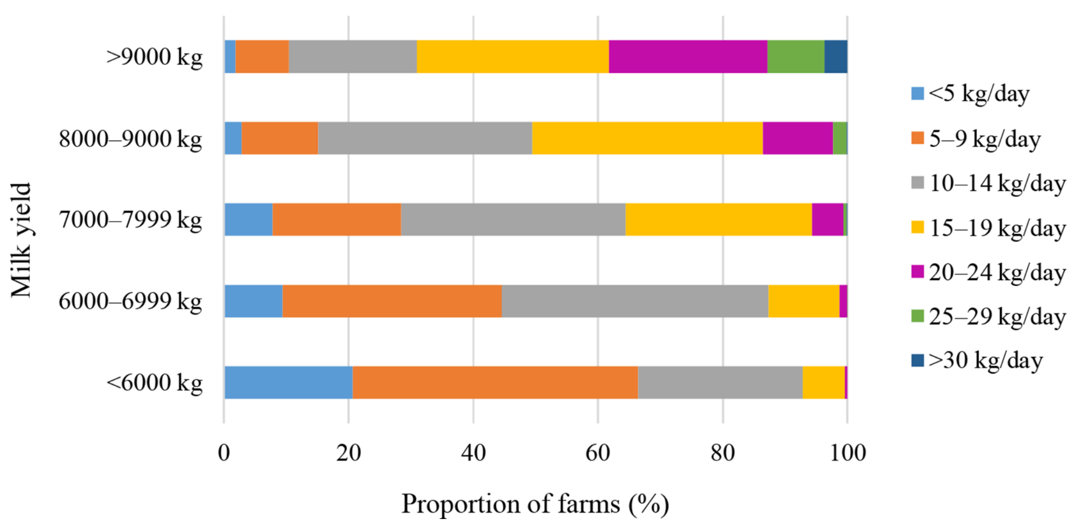

Figure 4. Annual milk yield per cow in relation to the level of milk yield at dry-off (n = 508).

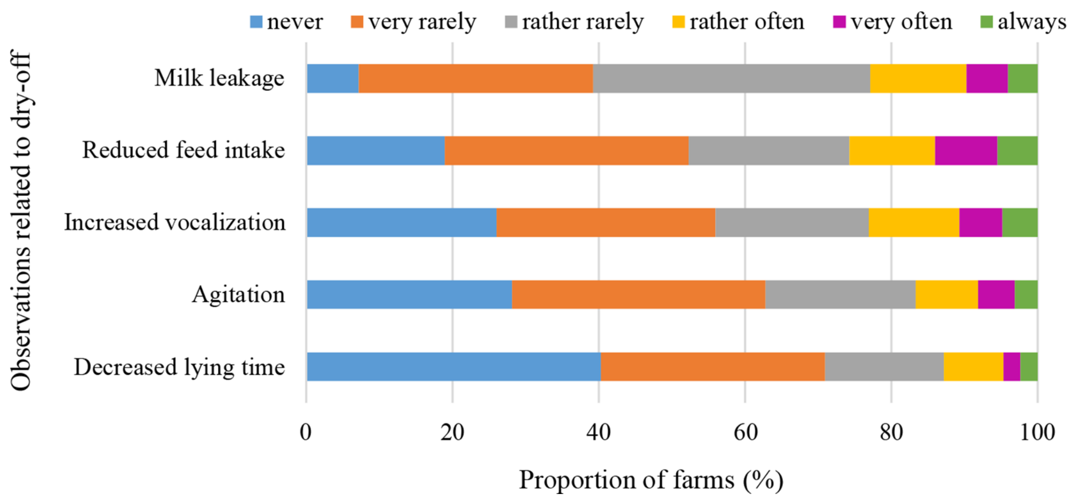

Figure 5. Frequency of observed milk leakage and behavioral changes of cows associated with dry-off (n = 518).

$P < 0.001$). When asked if they were willing to test this drying-off approach, 56.9% of the participants (295/518) indicated willingness to do so from "yes, rather likely" to "yes, definitely." The willingness to adopt increased to 69.1% (358/518) if an automated solution would be available in milking parlors or robots.

Spearman's rank correlation examined relationships between the willingness to test the presented approach and the characteristics of the farmer and the farm. A weak negative relationship was found between the age of the farmers and the willingness to test the approach, both in general ($r_s = -0.10$, $P < 0.05$, n = 518) and if it became available for automated use ($r_s = -0.14$, $P < 0.01$, n = 518). Another weak negative relationship was found between the average annual milk yield per cow and the willingness to test the approach in general ($r_s = -0.12$, $P < 0.01$, n = 518). The milking system used, from bucket, pipeline, parlor to AMS, correlated weakly positively with the willingness to test the approach if it became available for automated use ($r_s = 0.11$, $P < 0.05$, n = 508).

DISCUSSION

The online survey demonstrated a relationship between milk yield at dry-off and annual milk yield, and

Table 2. Frequencies and percentages of participants' spontaneous associations to the presented drying-off approach based on incomplete milking before dry-off after they had read the description of (a) the approach, and (b) application of this approach having no negative impact on udder health according to the current state of research

		Number of mentions (n = 521)	
Category	Examples	(a) After first description (%)	(b) After second description (%)
Animal welfare	Animal-friendly, animal welfare, less stress for cow	2 (0.4)	10 (1.9)
Antibiotics	Antibiotic use, less antibiotics, stronger antibiotics	1 (0.2)	5 (1.0)
Drying-off practice	Interval milking, once a day, gradual drying-off	6 (1.2)	4 (0.8)
Familiar	Familiar, grandfather's practice, my practice, not new, used in the past	30 (5.8)	30 (5.8)
Interest	Exciting, interesting, try out, worth considering	62 (12.0)	132 (25.5)
Milk	Legal requirements, milk delivery, milk quality, milk quantity	22 (4.2)	17 (3.3)
Naturalness	Calf, like calf, natural, nature, original	6 (1.2)	3 (0.6)
Negative evaluation	Senseless, stupid, unnecessary, wrong	39 (7.5)	40 (7.7)
Negative feasibility	Additional effort, complicated, labor-intensive, time-consuming	114 (22.0)	46 (8.9)
Neutral evaluation	No idea, matter of habit, okay, unsure, special	20 (3.9)	30 (5.8)
Positive evaluation	Beautiful, good, innovative, logical, right, super, wonderful	38 (7.3)	78 (15.1)
Positive feasibility	Feasible, functional, practicable, possibility	18 (3.5)	17 (3.3)
Skepticism	Doubts, skeptical, untrustworthy, questionable	14 (2.7)	33 (6.4)
Sticking to own practice	I change nothing anymore, I stick to my practice, my practice works	5 (1.0)	6 (1.2)
Technology	Automation necessary, milk meter necessary, milking robot	29 (5.6)	10 (1.9)
Udder health	Cell counts, mastitis, milk leakage, sepsis, udder pressure	69 (13.3)	26 (5.0)
Unfamiliar	Never heard of, new, no experience, unfamiliar	12 (2.3)	13 (2.5)
Other	Animal recognition, communication, difference	31 (6.0)	18 (3.5)

it revealed that 35% of cows produced considerable quantities of milk >15 kg/d at dry-off. The result is in accordance with the literature. Annual milk yields per cow have increased over the past few decades through genetic selection and improved nutrient and management practices (Barkema et al., 2015), which have consequently also led to high milk yields at dry-off. However, a targeted milk yield of 15 kg/d or less at dry-off is recommended to create good conditions for udder health and cow welfare during the dry period (Vilar and Rajala-Schultz, 2020). In our sample, 55% of farms intended to reduce milk production before dry-off by reducing milking frequencies or nutrient intake or both in combination. In comparison, in Finland, Vilar et al. (2018) reported that milking frequency was gradually reduced on 96% of the farms, with cows producing more than 15 kg/d at dry-off on only 14% of the farms. In contrast, abrupt cessation of milking is a common practice on farms in the United States (USDA, 2016), Scotland (Fujiwara et al., 2018), and Germany (Bertulat et al., 2015). In our sample, high milk yields at dry-off were common in high-yielding cows despite the frequent use of gradual dry-off, indicating the need to further reduce milk yield.

Farmers use antibiotic DCT to cure existing IMI and to prevent new infections in the dry period (Berry and Hillerton, 2002), but increasing concerns about antimicrobial resistance have required more prudent and reduced use of antibiotics (European Union, 2018). In our sample, blanket DCT was used on 12% of farms. An online survey from 2011 with more than 1,000 Swiss dairy farmers keeping a minimum of 11 cows, as in our study, reported that blanket DCT was used on 56% of farms (Gordon et al., 2012). Although the administration of blanket DCT has declined since 2011, 44% of our participants reported using antibiotics for drying-off rather often to always. In Switzerland, farmers generally receive a bonus when their bulk milk SCC is <100,000 cells/mL. This milk quality payment system is intended to motivate farmers to improve their milk quality, which may result in an incentive to use more antibiotics. However, increased milk yield at dry-off could also be a reason for frequent antibiotic use at dry-off. We found that high annual milk yields were associated with more frequent use of antibiotics at dry-off. Our results are consistent with those of Wittek et al. (2018), who found that annual milk yields in Austria were significantly higher in cows that received an antibiotic treatment at dry-off (7,920 ± 1,816 kg) than in cows that did not receive an antibiotic treatment (7,471 ± 1,770 kg). Their study showed an almost linear increase between the likelihood of using antibiotics at dry-off and the milk yield at the end of lactation (Wittek et al., 2018).

Adverse effects of drying-off practices on cow welfare and health were demonstrated in several studies (Odensten et al., 2005; Zobel et al., 2015; Vilar and Rajala-Schultz, 2020). Farmers in our study also reported observing milk leakage and changes in behavior of their cows associated with dry-off. Although participation in the survey was anonymous, it is important to bear in mind that farmers may not answer questions about sensitive issues such as animal welfare and antibiotic use truthfully or may not even be aware of changes in cow behavior. Therefore, changes in cow behavior, even if they were not very frequently reported as being observed, are worth discussion and further investigation in future research.

Our results offer the opportunity to discuss observations of milk leakage, increased vocalizations, and decreased lying time associated with dry-off in more detail. First, milk leakage poses a risk to udder health because the likelihood of developing new IMI is higher for cows with milk leakage than for cows without milk leakage (De Prado-Taranilla et al., 2020). The risk of developing milk leakage after dry-off increases with higher milk yield at dry-off (Bertulat et al., 2013; Gott et al., 2016; De Prado-Taranilla et al., 2020). About one quarter of our participants reported observing milk leakage associated with dry-off rather often to always, but increased annual milk yields were not significantly associated with the frequency of observed milk leakage. Consistent with our findings, De Prado-Taranilla et al. (2020) also did not observe a significant association between 305-d milk production and milk leakage, although milk production before dry-off was associated with milk leakage. Therefore, the authors suggested that most milk leakage after dry-off may be prevented if milk production in high-yielding cows is reduced before dry-off (De Prado-Taranilla et al., 2020). Second, increased vocalizations were observed when cows were fed a nutrient-restricted diet before dry-off, likely due to hunger (Valizaheh et al., 2008; Tucker et al., 2009; Franchi et al., 2021). Furthermore, feed restriction before dry-off can induce a transient negative energy balance (Odensten et al., 2005) and may weaken the immune system, thus, increasing susceptibility to IMI and other infections (Ollier et al., 2015; Lacasse et al., 2018). Increased vocalization at dry-off might also be due to high milk production at dry-off as our results showed a positive relationship between high annual milk yields and the frequency of observed vocalization associated with dry-off. Consistent with our findings, Silanikove et al. (2013) associated increased vocalizations with pain due to engorgement of the mammary gland when cows were dried-off abruptly while still producing more than 25 kg of milk per day. Third, decreased lying time was associated with signs of discomfort and pain due to milk accumulation and udder pressure induced by skipped milkings (Österman and Redbo, 2001; O'Driscoll et al., 2011). In addition, cows with high milk yield at dry-off had significantly shorter daily lying times after dry-off than cows with lower milk yield (Zobel et al., 2013; Rajala-Schultz et al., 2018), which is in agreement with our finding about the positive relationship between annual milk yields and observed decreased lying time associated with dry-off. However, recent studies suggested that changes in lying behavior at dry-off might result from management changes (Dancy et al., 2019) and, at least in part, from increased feeding time (Zobel et al., 2013). In summary, a need exists for alternative drying-off practices that reduce milk production before dry-off without compromising cow welfare and health.

Therefore, incomplete milking was introduced as an alternative approach to reducing milk production before dry-off in our study. Overall, analyzing the farmers' responses revealed various drivers and barriers for the adoption of incomplete milking for drying-off. The most important driver for adoption is that farmers generally showed willingness to test the presented approach. Farmers showed even more willingness to test the presented approach if it became available for automated use in milking parlors or robots. A further interesting driver is that incomplete milking before dry-off was a practice that was already known to some participants. This approach was referred to as "grandfather's practice" and, according to the participants, is already being used manually in some cases. The third driver to mention is a change in Swiss legislation in 2020. Farmers do not need to worry about delivering milk when incomplete milking is applied because it is no longer forbidden by legal regulations (Ordinance on Food of Animal Origin, 2020). The further development of the software module to reduce milk production automatically in milking parlors or robots before dry-off seems to be promising for the future.

The main barrier for adoption of the incomplete milking approach before dry-off involves uncertainties regarding udder health. These uncertainties may be based on the assumption that remaining milk in the udder could serve as substrate for pathogens, thereby endangering udder health. However, Martin et al. (2020) observed no increase in SCC or positive bacteriological finding when incomplete udder emptying of healthy udders was applied before dry-off. Similarly, other studies reported only short-term or slight increases in SCC from incomplete milking (Penry et al., 2017; Albaaj et al., 2018). Manual early cluster removal during the first 5 DIM was even shown to increase the odds of a decreased SCC from 11 to 18 DIM and had no effect on clinical mastitis incidence (Krug et al., 2018a). Moreover, ultrasonographic scans of the teats showed less change in teat morphology when the duration of milking time was reduced in incompletely milked cows compared with control cows (Martin et al., 2020). Milking time was halved by using the software module, which presumably reduced the intensity of strain on the teat tissue (Martin et al., 2020). Previous studies have demonstrated that the impact of the milking machine on the teat tissue increases toward the end of milking when the milk flow and the intramammary pressure decrease to almost zero (Besier and Bruckmaier, 2016; Odorčić et al., 2019). Shortening the milking time by early cluster removal may thus prevent increased strain on the teat at the end of milking.

It must be emphasized that the incomplete milking approach has been tested for drying-off only in cows with good udder health on research farms (Martin et al., 2020). Therefore, further research is needed to test the application under practical farm conditions. The effect of incomplete milking before dry-off on milk composition has also not been studied to date, but because not all cows are likely to be dried-off at the same time, detectable changes in milk composition in bulk milk are unlikely. In addition, incomplete milking during the first 5 DIM had negligible effects on milk composition (Krug et al., 2018b).

Our study contributes to the knowledge on currently implemented drying-off practices on Swiss farms and future perspectives of the adoption potential of incomplete milking before dry-off, but its limitations should also be taken into account. First, our data were collected through a survey, which means that they are retrospective and based on farmers' estimates and recall. This self-assessment could have introduced bias into the data. However, given that participation in the survey was voluntary and anonymous, we assume that the information was provided to the best of the farmers' knowledge and conscience. Second, the type of the question may also lead to bias and lack of accuracy in the data. To address this, the survey was sent to pretesters before its use for data collection to make sure it was comprehensible. Furthermore, technical advice and specific examples of how to answer the individual questions were provided. Third, it is possible that the farmers who participated in the survey were more open to alternative drying-off approaches. This self-selection bias is likely to be small because of the high participant rate of more than 500 farmers. The number of participants is a strength of the study. Because the data were collected from Swiss dairy farmers with relatively small dairy herds, they are especially representative for countries with predominantly small-scale dairy farms.

Our results suggest that farmers would be interested in a commercial and automated application of the software module of the drying-off approach in the milking parlor or robot. Our sample showed that farms with high-yielding cows more often had milking systems with higher level of automation such as AMS and parlors, which would allow an automated application of the incomplete milking approach. Furthermore, the annual milk yield had a strong positive correlation with the number of dairy cows on a farm. Dairy farmers with larger herd sizes, especially with more than 500 cows, adopted more precision dairy technology than farmers with less than 500 cows (Gargiulo et al., 2018). Given that 69% of the responding farmers, who kept an average of 39 dairy cows, were willing to test the presented drying-off approach if it became available for automated use, then interest is likely to be present among farmers who have significantly more cows. This information is crucial for the further development of the software module for automated application of incomplete milking before dry-off and for future studies to build on.

CONCLUSIONS

In establishing the status quo of drying-off practices, the need for alternative approaches to reduce milk production before dry-off while maintaining cow welfare was identified. Farmers in our study expressed interest in testing the presented alternative approach based on incomplete milking, especially if uncertainties regarding udder health could be removed. In addition, farmers indicated that they would be more willing to test the incomplete milking approach before dry-off if it became available for automated use in milking parlors or robots. This finding is a novel and valuable contribution to the further development of the software module for automated application. Furthermore, adoption of incomplete milking could help decrease antibiotic use at dry-off while maintaining cow health and welfare by reducing milk production before dry-off.

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