Consequences of Lactation Length Management for Health and Fertility in Dairy Cows

Production diseases in farm animals

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Consequences of Lactation Length Management for Health and Fertility in Dairy Cows

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Abstract

Extending lactation length, as well as shortening or omitting the dry period have interesting perspectives on health and fertility of high-producing dairy cows. By extending lactation length, the frequency of critical calving events for the cow reduces, herewith reducing the frequency of periods with increased risk for health problems. Alternatively, shortening or omitting the dry period reduces the number and magnitude of peripartum transitions for the cow, with less milk and a better energy balance after calving. Potential risks of these management strategies are that milk yield of cows at the end of lactation is too low to extend the lactation period, and that cows fatten in late lactation. Therefore, both extending lactation length and shortening or omitting of the dry period might not fit every cow. Individual cow characteristics like parity, milk yield level, body condition, or health status contribute to the response of the cow to an extended lactation or shortened or omitted dry period. These individual cow characteristics can be used in customized management strategies to optimize lactation length or dry period length for individual cows. Customized lactation or dry period length could limit the impact at herd level of disadvantages concerning milk losses and body fattening and maintain benefits for improved cow health and fertility, reduced number of surplus calves, and increased work satisfaction for the farmer.

Keywords

Dry period length · Extended lactation · Voluntary waiting period · Continuous milking · Metabolic status · Metabolic disorders · Reproductive performance · Individual cow variation

1 Traditional Lactation Cycle in Dairy Cows

The lactation cycle of dairy cows traditionally consists of a lactation period of about 10 months followed by a non-lactating, or so-called dry period, of 6–8 weeks. This yearly lactation cycle is likely based on the nature of ruminants, with a calf every spring and forage availability matching the energy requirements of the dam and her calf (Balasse et al. 2021). Also, the dry period of dairy cows has a long tradition, built on the experience of dairy farmers and noted as such in handbooks of the early 1900s (Dix Arnold and Becker 1936). Possibly, the dry period in those days was not a

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farmer's decision or deliberately management strategy, but a consequence of the lower milk production level of dairy cows.

Later, several research groups focused on determining the optimal lactation length (e.g., Dijkhuizen et al. 1985; Schmidt 1989; Strandberg and Oltenacu 1989) or dry period length (Keown and Everett 1986; Kuhn et al. 2006a) for dairy cows. Almost without exception, these studies used a retrospective approach and focused solely on the consequences of milk production. An advantage of these retrospective studies is that they benefit from the power of large datasets and objective monitoring of milk yield of individual cows in a large number of herds. A disadvantage of these retrospective studies is that these large datasets lack information on the reasons why cows had a short or long lactation, or short or long dry period, and that they did not incorporate consequences for health and disease.

More recently, there has been a growing debate concerning the optimal lactation length (Knight 2005) or dry period length (Grummer and Rastani 2004) of high-producing dairy cows. An important driver for this debate is the high production potential of modern dairy cows, with an increased capacity to maintain a high milk yield towards the end of lactation, and the increasingly challenging drying-off process of cows. With an extended lactation or without a dry period, cows could realize more milk in the current lactation and drying-off could be postponed to lower yield levels or avoided (Fig. 1). Moreover, both extending the lactation length as well as shortening the dry period length have interesting perspectives for metabolic status and health of high-producing cows in the peripartum period.

1.1 Health Challenges in the Transition Period

Conventionally, the transition period for dairy cows is defined as the period from 3 weeks before calving to 3 weeks after calving (Drackley 1999). This transition period is not only related to a change in physiological status from pregnancy to lactation, but also with regrouping from dry to lactating cows, a change in ration to support lactation and changes in daily routine associated with milking. Moreover, even before the transition period starts, the transition from lactation to the dry period imposes a challenge to health and welfare of dairy cows (Zobel et al. 2015). High milk production at dry-off is not only related to greater udder pressure after dry-off and increased fecal glucocorticoid concentration indicating compromised cow welfare (Bertulat et al. 2013), but also with more milk leakage (Bertulat et al. 2013) and increased risk for new intramammary infections after the next calving moment (Rajala-Schultz et al. 2005).

Each transition period for dairy cows is characterized by an adaptation process to a new physiological state and new housing, ration, and management conditions. Lack of adaptation during a transition period entails an increased risk for compromised health and fertility (The Lancet 2009) or potentially culling and a reduced productive life (Pinedo et al. 2014; Fig. 2). Furthermore, etiology of a negative energy balance and health problems in the peripartum period can be traced back to management and physiology of cows during the transitions from lactation to dry period to calving and start of a new lactation (as reviewed by Ingvartsen 2006; Van Knegsel et al. 2014a).

1.2 Aim of This Chapter

With extending the lactation length the frequency of the transitions for the cow reduces, herewith reducing the frequency of periods with increased risk for health problems and reducing the milk yield at dry-off. Alternatively, shortening or omitting the dry period partly avoids these transitions, e.g. when the dry period is completely omitted, and at the same time reduces the magnitude of peripartum transitions with less milk and a better energy balance after calving (Fig. 2).

This chapter focuses on consequences of lactation length and dry period length for milk production, metabolic status, and health and fertility of dairy cows, with a specific focus on production diseases. Moreover, consequences for calves are discussed, as well as customized management

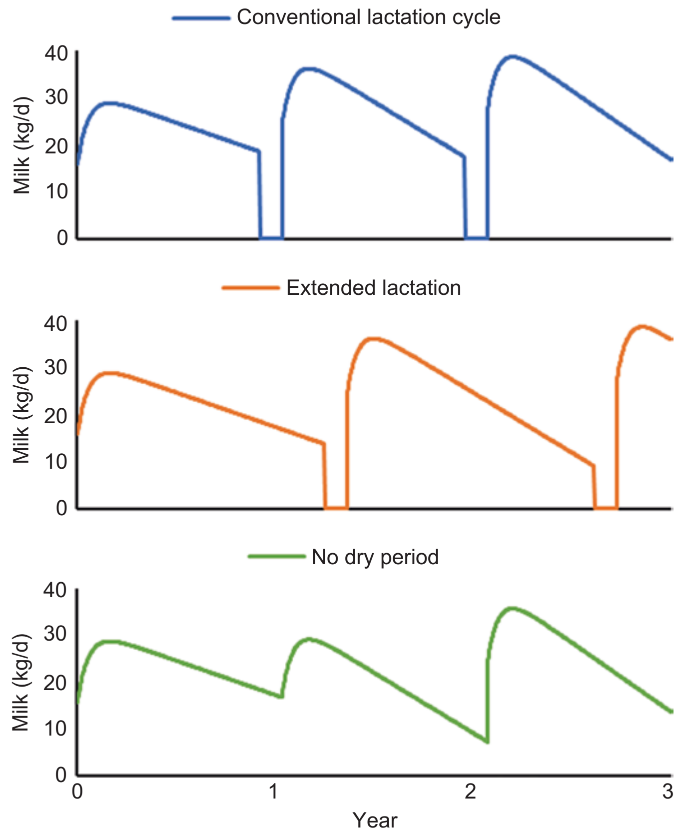

Fig. 1 Schematic representation of milk production over 3 years following first calving for a conventional lactation cycle, a lactation cycle with an extended lactation, and a lactation cycle without a dry period

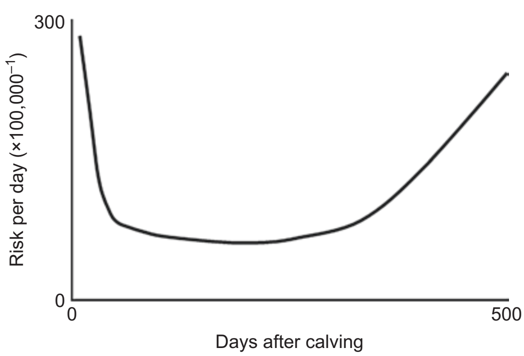

Fig. 2 Culling risk by days after calving for Holstein dairy cows. Adapted from Pinedo et al. 2014. Culling risk early in lactation was mainly related to culling reasons death, injury or sickness, and mastitis. The increase in culling risk from about 300 days after calving was related to culling reasons "low productivity" and breeding, thus seemed related to subfertility and selection by the farmer

approaches, where performance of individual cows is optimized with a specific lactation or dry period length.

2 Lactation Length

In most conventional dairy systems, dairy farmers are advised to aim for a 1-year calving interval (CI), with a yearly calving moment, a yearly peak in milk production and a yearly period with increased risk for disease (Pinedo et al. 2014; Koeck et al. 2015). Originally this yearly calving event might be based on the nature of ruminants, with calves being born in spring when feed availability is abundant (Balasse et al. 2021). Later this advice was further supported by retrospective modelling studies focusing on consequences of lactation length for milk yield (Dijkhuizen et al. 1985; Strandberg and Oltenacu 1989), but lacked impact on cow health, fertility, and farm labor. In the last two decades, the traditional 1-year CI has been increasingly debated because of increased productivity of dairy cows (Knight 2005), health and welfare risks associated with the transition period (Knight 2005), and the more recent debate concerning surplus calves in the dairy sector (Bolton and Von Keyserlingk 2021).

Extending the voluntary waiting period (VWP) can be a strategy to deliberately extend the lactation length and CI of dairy cows. The VWP is the interval after calving during which farmers decide not to inseminate the cow, even if she is seen in estrous. The VWP gives the uterus time to recover from calving, recover from any peripartum infection, and return to its normal involuted state. Traditionally farmers apply a VWP of 40–60 days, aiming at a 1-year CI to maximize milk revenues (Österman and Bertilsson 2003). Deliberately extending the VWP can be a strategy to postpone artificial insemination for cows with high production potential or compromised fertility in early lactation, to reduce the number of calving moments with associated risks and reduce milk yield at dry-off.

2.1 Metabolic Status

Longer lactations result specifically in a longer period in late lactation with a relatively lower milk yield, and a smaller proportion of days dry. This implies that consequences of extended lactations for milk yield depend on the capacity of the cow to maintain her milk production, or lactation persistency. For multiparous cows, extending the lactation by extending the VWP resulted in a reduction in milk yield per day of CI (Rehn et al. 2000; Burgers et al. 2021a). Primiparous cows, however, have greater lactation persistency than multiparous cows (Burgers et al. 2021a). As a consequence, extending the VWP for primiparous cows had no effect on milk yield per day of CI (Rehn et al. 2000), or increased milk yield per day of CI in other studies (Arbel et al. 2001; Stangaferro et al. 2018b).

Fattening of dairy cows in late lactation is a risk for cows with a longer lactation, resulting in a greater BCS at dry-off for cows with an extended lactation (Niozas et al. 2019b; Jarman et al. 2020). In another study, specifically multiparous cows, and not primiparous cows, had a greater body condition score (BCS) in the last 3 months before dry-off when the VWP was extended to 200 d, compared with a VWP of 50 d (Burgers et al. 2021a).

Increased BCS at the end of lactation can be a risk factor for a hampered start of the new lactation with a more severe negative energy balance and increased risk for metabolic disorders like ketosis and liver fattening (Morrow 1976). Multiparous cows, but not primiparous cows, with an extended VWP of 200 d and an increased BCS at dry-off had greater plasma non-esterified fatty acid and β-hydroxybutyrate concentrations in the first 6 weeks after the subsequent calving (Burgers et al. 2023). This indicates that when the extended VWP is related to increased BCS at the end of lactation there is a risk for a more compromised metabolic status and more severe negative energy balance after the subsequent calving.

Dietary measures can potentially limit the increase in BCS towards the end of lactation of cows with an extended VWP. Dietary measures to limit fattening of cows in late lactation can either aim to limit energy intake or improve milk production and lactation persistency in late lactation. Feeding a high-energy level in early lactation, aiming at an improved lactation persistency in the complete lactation, however, had a negative carry-over effect on the persistency later in lactation, compared with a standard energy level (Gaillard et al. 2016). On the contrary, a pasture-based diet resulted in a greater proportion of cows milked until the planned time of dry-off, greater milk solid production, and lower body fattening, compared with a TMR diet for cows managed for an extended lactation (Grainger et al. 2009).

2.2 Reproduction

Extending the VWP gives cows, and specifically their reproductive system, more time to recover from calving, start of lactation and the negative energy balance, and can therefore be expected to improve reproductive performance. Consequences of an extended VWP for reproduction are, however, not unequivocal (Fig. 3). Cows with an extended VWP in some studies had

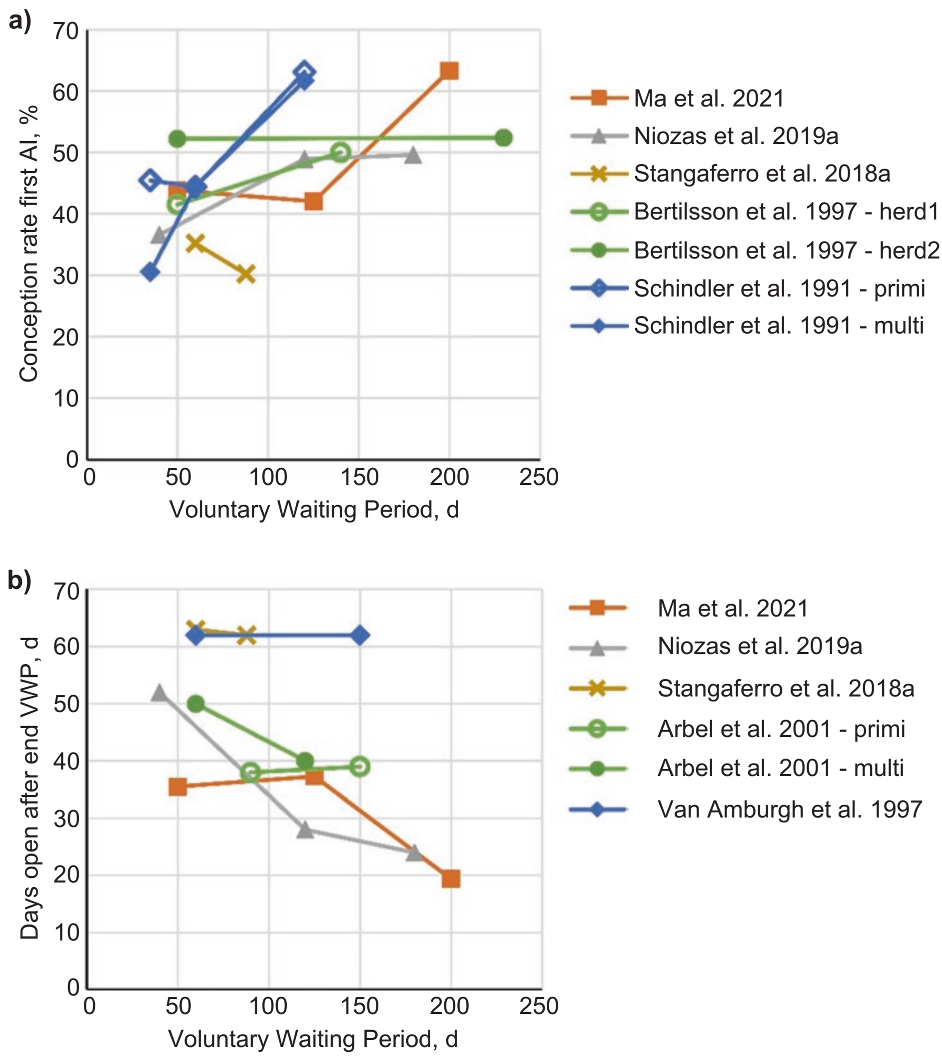

Fig. 3 Conception rate first AI (**a**) and days open (**b**) after the end of the voluntary waiting period (VWP) for cows that were pregnant per VWP in each experiment (Van Knegsel et al. 2022)

higher conception rates at first AI, and fewer days open after the end of the VWP; though other studies found no effect of VWP on these variables. Differences among studies could be related to (1) Parity of the cows, with no improvement of reproductive performance in primiparous cows (Arbel et al. 2001); (2) Differences in management protocol, i.e., days open after end of the VWP was not reduced when cows were insemination after an estrous synchronization protocol (Stangaferro et al. 2018b) or lactations were managed with use of bovine somatotropin to stimulate milk production (Van Amburgh et al. 1997) or (3) Extent of the VWP contrast and consequences of the VWP extension for body condition.

An improved reproductive performance after extension of the VWP can be hypothesized to be due to more time to resume ovarian cyclicity or a lower milk yield and better metabolic status during the breeding period. Extension of the VWP to 125 or 200 d resulted in a greater percentage of normal ovarian cycles (18–24 d in length) during the 100 d around the end of the VWP, compared with a VWP of 50 d (Ma et al. 2022). In this same experiment, milk yield was lower and plasma insulin and IGF-1 concentration were greater for multiparous cows around the end of the extended VWP, indicating a better body condition and metabolic status during the breeding period for cows with an extended VWP (Burgers et al. 2023).

2.3 Disease and Welfare

A major reason to deliberately extend the lactation length by extending the VWP is the potential benefits for health and welfare of cows. Extending the VWP reduces the frequency of critical calving moments for the individual cow and within a herd, which can be expected to be beneficial for cow health. Limited studies, however, reported disease incidence of cows with different VWP or deliberately extended lactations. In our earlier experiment, disease treatments did not differ among cows with a VWP of 50, 125, or 200 d (Table 1). Numerically, however, more disease treatments were recorded per lactation, but fewer disease treatments were recorded per year, for cows with longer VWP treatments.

Extending the lactation also reduces the frequency of transitions from lactation to dry-off and the milk yield at dry-off (Niozas et al. 2019b). Milk yield at dry-off of cows with a VWP of 180 d was 16.9 kg/d compared with 19.1 kg/d for cows with a VWP of 40 d, and the proportion of cows with milk yield below 15 kg/d was increased from 34% to 54% (Niozas et al. 2019b). The low milk at the end of the extended lactation for cows with an extended VWP can be expected to reduce

Table 1 Disease treatments for a complete lactation (6 weeks after calving until 6 weeks after next calving) (a) and disease treatments per year (b) per treatment group of cows with a voluntary waiting period (VWP) of 50, 125, or 200 d (Van Knegsel et al. 2022)

(a)	VWP50	VWP125	VWP200	Total
Number of cows	53	49	51	153
Milk fever	10	17	9	36
Ketosis	1	1	3	5
Clinical mastitis	28	25	31	84
Retained placenta	4	1	4	9
Vaginal discharge	8	8	7	23
Endometritis	5	4	6	15
Cystic ovaries	11	8	19	38
Claw and leg problems	47	67	48	162
Stomach and intestine problems[a]	14	22	15	51
Other[b]	8	14	14	36
Total	136	167	156	459

(b)	VWP50	VWP125	VWP200	Total
Number of cows	53	49	51	153
Milk fever	10	14	7	31
Ketosis	1	1	2	4
Clinical mastitis	28	21	24	73
Retained placenta	4	1	3	8
Vaginal discharge	8	7	5	20
Endometritis	5	3	5	13
Cystic ovaries	11	7	15	33
Claw and leg problems	47	56	37	140
Stomach and intestine problems[a]	14	18	12	44
Other[b]	8	12	11	31
Total	136	140	121	397

[a]Main stomach and intestine problems: rotavirus, diarrhea, peritonitis
[b]Main diagnoses in "other": fever, cobalt deficiency, 3 teats

udder pressure and benefit cow welfare at dry off (Bertulat et al. 2013), and reduce the risk for new intramammary infections at start of the subsequent lactation (Rajala-Schultz et al. 2005).

There are, however, also potential risks of an extended VWP and an extended lactation for cow health. The risk for fattening of cows end of the extended lactation and a compromised metabolic status at the start of the subsequent lactation (Burgers et al. 2023) were already discussed in this chapter. In addition, several studies report a rise in SCC toward the end of an extended lactation (Sorensen et al. 2008; Niozas et al. 2019b; Ma et al. 2021). None of these studies, however, report an effect of an extended lactation for mastitis incidence. This indicates that the rise in SCC at the end of an extended lactation is probably not due to more cases of clinical mastitis, but is likely related to the lower milk yield or reduced epithelial integrity at the end of an extended lactation.

2.4 Calves

Extending the lactation length by extending the VWP reduces the number of calving moments and herewith reduces the number of calves born per time unit. Fewer calves born were a major motivation for 13 commercial farmers to extend the VWP in their herd (Van Dooren 2019). First, fewer calving events reduce labor associated with calving and management of neonatal calves and fresh cows. Second, a reduction in number of calves born per year reduces the number of surplus calves that will be mostly transported to the veal industry. These surplus calves are of growing concern not only for farmers but also in science, politics, and society, because of the welfare impact of transport of these calves at a young age and debated management approaches for these young calves (Bolton and Von Keyserlingk 2021).

Extending the VWP not only impacts management of calves, but also hypothetically impacts health and development of the calves born in the herd. Extending the VWP implies that cows are inseminated during a later moment in lactation, where milk production is lower and body condition and metabolic status are improved, compared with insemination earlier in lactation (Burgers et al. 2023). In other species, it is well known that the metabolic status of the dam around conception can have long-term consequences for health and metabolic status of the offspring (as reviewed by Fleming et al. 2018). In dairy cows, milk production level of the dam during the breeding period was negatively related to milk production and survival of the offspring (Berry et al. 2008). Future studies should evaluate the consequences of metabolic status of the cow during the conception period on health and development of her calf during early and later life.

2.5 Customized Lactation Length

Although extending the VWP can benefit cow health and fertility, there are also potential tradeoffs of an extended VWP with respect to low milk yield and fattening of cows at the end of the lactation. Moreover, the response of cows to an extended VWP depended on individual cow characteristics. In practice, dairy farmers recognized that not all cows are suited for an extended VWP (Burgers et al. 2021b). In this earlier study, the strategy to extend the lactation by extending the VWP varied among farmers. Some farmers (3/13) applied a fixed VWP for the whole herd. Most farmers (10/13) applied a customized strategy based on individual cow characteristics like parity, milk yield level, body condition, or a combination of cow characteristics. As a result, cows with a short calving interval at these farms had a lower peak milk yield and lower 305-d milk yield, while cows with a longer calving interval had a greater 305-d milk yield and a more persistent lactation curve. So farmers seem to select cows with a high milk yield for an extended lactation (Lehmann et al. 2017; Burgers et al. 2021b) to ensure milk yield toward the end of the lactation, limit the risk for body fattening, but possibly also due to the greater benefit of reducing milk yield at dry-off and reducing the frequency of critical calving events specifically for high-producing cows.

The response of individual cows to a VWP was not only evaluated in observational studies (Lehmann et al. 2017; Burgers et al. 2021b), but also in a randomized controlled trial (Burgers et al. 2021a). Parity, milk yield level, and shape of the lactation curve in both the previous and early lactation and body weight predicted the fat-and-protein correct milk yield per day calving interval of cows with different VWP (Burgers et al. 2021a). Moreover, not VWP, but milk yield level, milk composition, and disease treatments determined the net economic result of individual cows with different VWP (Burgers et al. 2022). Until now, especially on-farm cow characteristics were evaluated concerning the prediction of the individual cow response to different VWP. It can be hypothesized that also health characteristics or metabolic status of cows in early lactation is related to the response of cows to an extended VWP. At the moment, studies are ongoing to determine the value of metabolic variables in early lactation to predict the performance of cows in an extended lactation.

3 Dry Period Length

The dry period is the non-lactating period before (next) calving, which generally lasts 6 to 8 weeks in modern dairy farming systems. The dry period has multiple functions. First, cows with persistent intramammary infections can be treated with dry cows antibiotics (Bradley and Green 2001), Second, the dry period allows the cow a rest period before the next calving (Kok et al. 2017a). Third, a dry period of 6 to 8 weeks is associated with maximal milk yield in the next lactation (Kuhn et al. 2005, 2006b). During a dry period, renewal of mammary secretory cells is maximal, resulting in a high proportion of new secretory cells at the moment of calving (Capuco et al. 1997), which would clarify the peak in milk yield after calving (Capuco et al. 2001).

Shortening, and omitting, the dry period in dairy cows reduces milk yield after calving, but increases milk yield in the period before calving, when the cow can meet the energy demands for milk production easily (Rastani et al. 2005; Van Knegsel et al. 2014a; Fig. 4a). The reduction in energy partitioned to milk after calving resulted in a better energy balance in early lactation (Rastani et al. 2005; Van Knegsel et al. 2014a; Andrée O'Hara et al. 2018), as earlier reviewed (Kok et al. 2019) (Fig. 4b). Omitting and shortening the dry period resulted in similar or increased dry matter intake in early lactation (as reviewed in Van Knegsel et al. 2013). Reasons for an improved dry matter intake with a short or no dry period are not completely known, but can be speculated to be related to fewer changes in daily routine, ration, and social group, or a less positive energy balance in the precalving period resulting in lower body condition score at calving (Grummer et al. 2004; Rastani et al. 2005). So, shortening and omitting the dry period results in a better energy balance after calving, which is mainly due to the lower milk yield after calving.

3.1 Metabolic Status

The better energy balance in early lactation of dairy cows with no or a short dry period is partially reflected in the metabolic status of dairy cows in early lactation. Cows with no dry period had lower plasma non-esterified fatty acids (NEFA) and beta-hydroxybutyrate (BHB) concentrations than cows with a conventional dry period (Rastani et al. 2005; Andersen et al. 2005; Klusmeyer et al. 2009; Chen et al. 2015a), indicating less body fat mobilization and less incomplete hepatic fat oxidation. Moreover, cows with no dry period had greater plasma glucose, insulin, and IGF-1 concentration (Andersen et al. 2005; De Feu et al. 2009; Chen et al. 2015a), mirroring the better body condition in these cows, compared with cows with conventional dry period. Also, a short dry period sometimes reduced plasma NEFA and BHB concentration in early lactation compared with a conventional dry period (Pezeshki et al. 2007; Klusmeyer et al. 2009), but not in all studies (Rastani et al. 2005; Chen et al. 2015a).

Shortening and omitting the dry period not only resulted in a better energy balance in early lactation but also in a better energy balance (Van

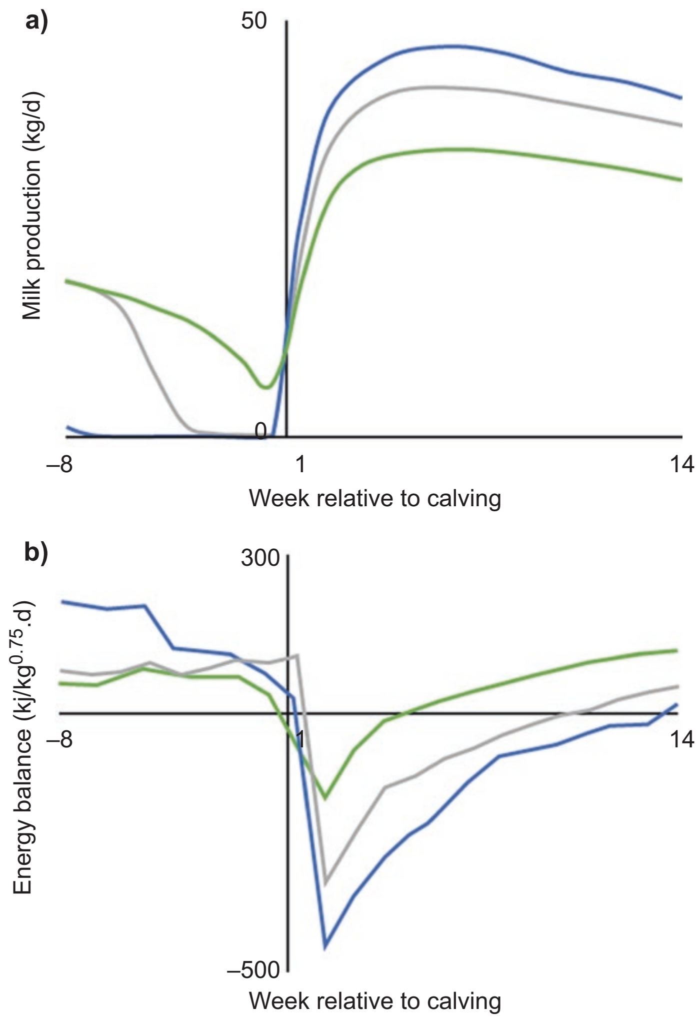

Fig. 4 Milk production and energy balance from week 8 to 14 relative to calving for cows with a standard (blue), short (grey), or no (green) dry period. Adapted from Van Knegsel et al. (2014b)

Hoeij et al. 2017) and greater body weight (Chen 2016) in mid and late lactation, due to a lower milk output and similar energy intake. The more positive energy balance poses a risk for body fattening in mid and late lactation, with potentially negative consequences for energy balance and metabolic status after the subsequent calving (Chen et al. 2016). To our knowledge, almost all experimental studies evaluated consequences of dry period length while feeding the same energy level during lactation. This made sense from a scientific perspective, avoiding confounding effects of diet and dry period length in the experimental set-up and not limiting the production capacity of cows with a short or no dry period due to feeding a lower energy level in the diet. Under practical circumstances, however, farmers might adjust their diets based on dry period length or expected milk yield. Feeding a lower energy level in early lactation did not affect milk yield or plasma NEFA or BHB concentration, but indeed reduced the positive energy balance in early lactation of cows after no dry period (Van Hoeij et al. 2017).

3.2 Reproduction

In some studies, omitting and shortening the dry period reduced the interval between calving and onset of luteal activity (Gümen et al. 2005; Watters et al. 2009) and improved the regularity of subsequent ovarian cycles (Chen et al. 2015b). However, in other studies omitting or shortening of the dry period did not significantly affect the conception rate and days open (Fig. 5). Differences among studies could be related to body condition of the cows, as cows with no dry period that had a high body condition score in early lactation had increased days open and reduced conception rates (Chen et al. 2017; Ma et al. 2020). Management, including voluntary waiting period, estrus detection, and insemination policy, could also affect reproductive results of cows after different dry period lengths.

3.3 Disease in Early Lactation

It can be expected that a lower milk yield, better energy balance, and better metabolic status in early lactation due to a short or no dry period

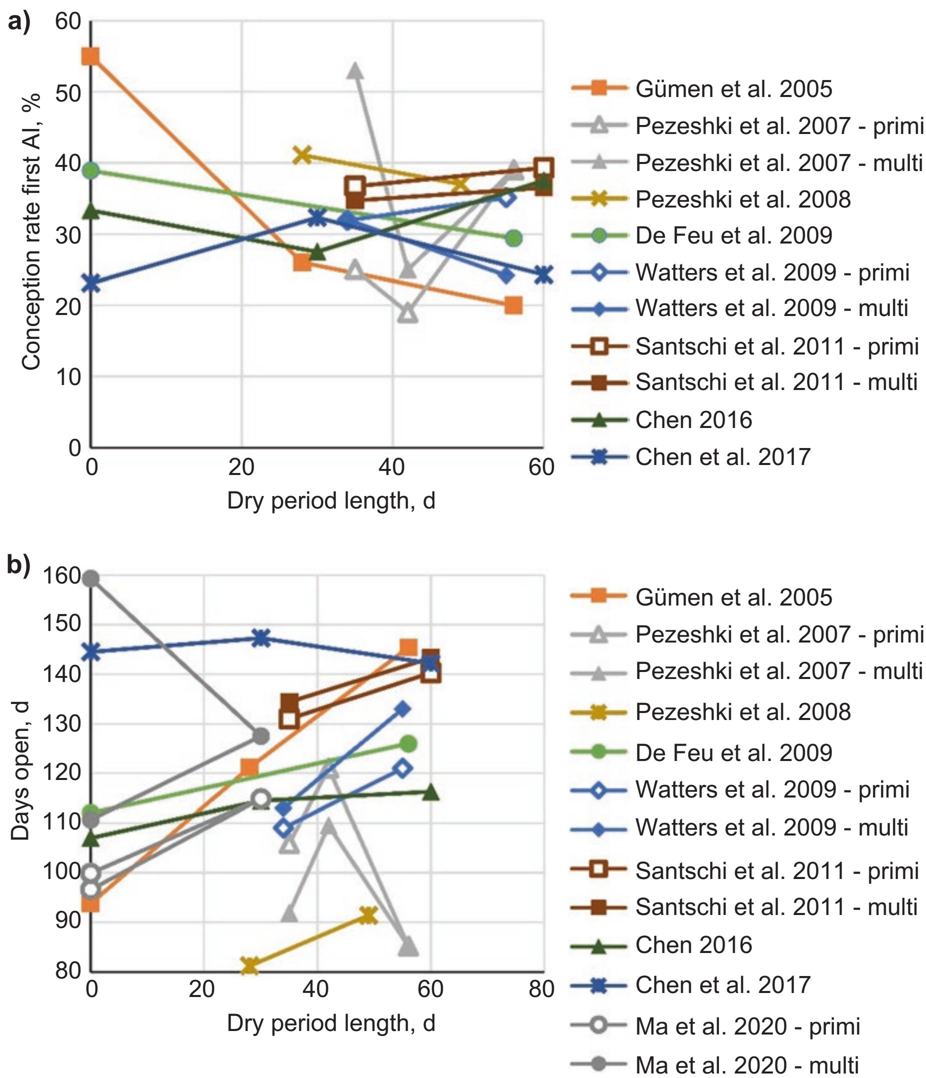

Fig. 5 Conception rate first AI (**a**) and days open (**b**) after different dry period lengths for cows per dry period length in each experiment. Note Chen et al. 2017: Cows in this study were subjected to a dry period of 0, 30, or 60 days for a second time, where dry period length was confounded with BCS prepartum and in early lactation. Note Ma et al. 2020: Cows with a 0-day dry period length were fed one of two energy levels

reduces the incidence of disease in early lactation. Limited studies, however, reported the disease incidence of cows with different dry period lengths. In a meta-analysis, shortening of the dry period tended to be associated with a lower odds for ketosis (OR = 0.75; P = 0.09), compared with a conventional dry period (Van Knegsel et al. 2013). Three studies reported that ketosis did not occur after no dry period, compared with a conventional dry period (Rastani et al. 2005; Schlamberger et al. 2010; Köpf et al. 2014). In the same meta-analysis, shortening of the dry period was not associated with incidence of metritis, retained placenta, and mastitis, compared with a conventional dry period (Van Knegsel et al. 2013).

3.4 Udder Health

Effects of dry period length on udder health are not univocal. Dry period length did not affect the incidence of mastitis in most studies (Santschi et al. 2011; Van Hoeij et al. 2016) nor in a meta-analysis including seven studies (Van Knegsel et al. 2013). In addition, shortening the dry period did not affect SCC after calving compared with a conventional dry period when cows were treated with dry cow antibiotics (Rastani et al. 2005; Pezeshki et al. 2007; Van Knegsel et al. 2014b). Omitting the dry period increased SCC after calving in some (Klusmeyer et al. 2009; Van Knegsel et al. 2014b; Van Hoeij et al. 2016) but not all studies (Rastani et al. 2005; Köpf et al. 2014).

Variation in reported effects of dry period length on udder health might be due to udder health status or immune status of the cows at the end of the lactation, drying off protocol, and other management measures on the farm related to hygiene. A higher SCC after omission of the dry period might be explained by three factors. First, milk yield after calving is lower when the DP is omitted, which reduces the dilution and consequently increases the concentration of the absolute number of cells in milk (Steeneveld et al. 2013). Second, renewal of udder cells during lactation might be increased when the DP is omitted (Annen et al. 2008), whereas renewal of udder cells would normally occur at a high rate during the DP (Capuco et al. 2001). Third, the greater SCC after no dry period might be related to uncured intramammary infections because of the lack of both a dry period and lack of treatment with dry cow antibiotics. To our knowledge, there are two studies that compared udder health of cows without a dry period with udder health of cows with a dry period without use of dry cow antibiotics. Both studies reported an increased risk for mastitis after a short dry period, compared with a conventional dry period (Andrée O'Hara et al. 2019) or an increased risk for mastitis after no dry period, when compared with cows with a dry period without use of dry cow antibiotics (Van Hoeij et al. 2018).

3.5 Calves

Calf health could be affected by shortening or omitting the dry period due to differences in physiology and management during late gestation or in colostrum composition during early lactation. Omission of the dry period reduced gestation length by 3 days, and the birth weight of calves by 1.5 kg, compared with a conventional dry period (Mayasari et al. 2015). A short dry period did not affect gestation length or birth weight.

After calving, no dry period resulted in a lower concentration of antibodies, both IgG and IgM, in colostrum compared with a short or conventional dry period (Rastani et al. 2005; Mayasari et al. 2015). The lower concentration of antibodies can be explained by antibodies being secreted in milk, instead of accumulating, in the days before calving (Baumrucker et al. 2014). The quantity of colostrum in case of a short dry period in most studies was sufficient to fulfil the needs of the calf (Rastani et al. 2005; Watters et al. 2008; Shoshani et al. 2014; Mayasari et al. 2015). The high variability in colostrum quality when the DP is omitted (Baumrucker et al. 2014), however, could imply that a larger quantity of colostrum is fed to calves to ensure an adequate intake of antibodies.

3.6 Customized Dry Period Length

Although shortening and omitting the dry period benefit energy status and fertility of dairy cows in the subsequent lactation, potential tradeoffs would be a milk yield reduction and loss of opportunity to treat cows with dry cow antibiotics. In addition, the response of dairy cows to a short or no dry period depended on individual cow characteristics. First, primiparous cows gave more milk in the current lactation when the dry period is omitted, but have a greater milk yield reduction after calving, compared with multiparous cows (Pezeshki et al. 2007; Van Knegsel et al. 2014b). Second, the effect of dry period length on SCC depends on SCC elevations and average SCC in the previous lactation and SCC at the last test day before dry-off (Van Hoeij et al. 2016). Third, high-producing cows can be considered to be better suited for shorter dry periods because they produce more additional milk before calving, are more difficult to dry off (Rajala-Schultz et al. 2005; Zobel et al. 2015), benefit more from an improvement in energy balance in the subsequent lactation, and proportionally have the lowest milk yield losses in the subsequent lactation (Kok et al. 2017b).

Customizing dry period length for individual cows might retain the benefits of shorter or no dry periods and limit the negative consequences at herd level. We evaluated two decision trees (Fig. 6) for dry period length and use of dry cow antibiotics based on parity, milk yield level, and SCC in late lactation, and compared these with a

Decision tree		67 days before expected calving		37 days before expected calving		Treatment
C	All	SCC ≥ 150.000				60AB
		SCC < 150.000				60TS
T1	Par 1	SCC ≥ 150.000				60AB
		SCC < 150.000	Yield < 12 kg/ d			60TS
			Yield ≥ 12 kg/ d			30TS
	Par >1	SCC ≥ 50.000				60AB
		SCC < 50.000	Yield < 12 kg/ d			60TS
			Yield ≥ 12 kg/ d	SCC ≥ 50.000		30TS
				SCC < 50.000	Yield < 12 kg/ d	30TS
					Yield ≥ 12 kg/ d	0d
T2	Par 1	SCC ≥ 200.000				60AB
		SCC < 200.000	Yield < 12 kg/ d			60TS
			Yield ≥ 12 kg/ d			30TS
	Par >1	SCC ≥ 200.000				60AB
		SCC < 200.000	Yield < 12 kg/ d			60TS
			Yield ≥ 12 kg/ d	SCC ≥ 200.000		30TS
				SCC < 200.000	Yield < 12 kg/ d	30TS
					Yield ≥ 12 kg/ d	0d

Fig. 6 Visualization of the dry-period strategies applied under control (CT), treatment 1 (T1), and treatment 2 (T2) decision trees. Combinations of dry-period length of 60, 30, or 0 d, and dry-cow therapy with antibiotics (AB) or teat seal (TS) depended on the SCC in cells/ mL on the last test day before the decision moment at 67 or 37 d before expected calving (adapted from Kok et al. 2021)

fixed dry period length in combination with selective dry cow antibiotics (Kok et al. 2021). In decision tree 1, 36% of the cows qualified for a short dry period of 30 d and 2% of the cows for no dry period. In decision tree 2, 51% of the cows qualified for a short dry period and 30% of the cows for no dry period. Compared with the control group, cows in both decision trees produced more milk in the 8 weeks before calving and less in the 14 weeks after calving. These differences were smaller than when all cows were given a short or no dry period (Van Knegsel et al. 2014a). There was no effect on SCC or mastitis incidence. Due to the larger proportion of short and no dry periods, cows in decision tree 2 had a greater body weight gain in the first 14 weeks of lactation compared with the control group and cows in decision tree 1. Fewer cows tended to be treated for diseases in the first 100 DIM in decision tree 2 (37%) compared with decision tree 1 (54%) and the control treatment (57%).

4 Conclusions and Future Perspectives

Both extending the lactation length and shortening or omitting the dry period can improve health and fertility of high-producing dairy cows. With extending the lactation length the frequency of critical calving events for the cow reduces, herewith reducing the frequency of periods with increased risk for health problems. Alternatively, shortening or omitting the dry period partly avoids the transitions for the cow around calving and at the same time reduces the magnitude of peripartum transitions with less milk and a better energy balance after calving. Potential risks of these management strategies are that the milk yield of cows at the end of lactation is too low to extend the lactation period possibly associated with body fattening at end of the lactation. Herewith, both extending the lactation length as well as shortening or omitting of the dry period might not fit every cow. Customized lactation or dry period length could limit the impact at herd level of disadvantages concerning milk losses and body fattening and maintain benefits for improved cow health and fertility, reduced number of surplus calves, and increased work pleasure for the farmer.

The current decision support models to assign individual cows to a VWP or dry period length are based on farmers' experience (Burgers et al. 2021b) or a single dataset from a randomized controlled trial (Kok et al. 2021). To move from prediction models to decision models applicable in dairy practice, these models should be validated under different field conditions. Moreover, fine tuning decision support models based on herd-specific characteristics or including other data sources, like sensor data, can advance the development, predictive value, and applicability of these decision-support models.

Customized management of cows does not end at the right and accurate selection of cows for a specific VWP or dry period length. As described above, dietary measures or selective use of dry cow antibiotics could potentially stimulate lactation persistency or limit body fattening of cows with an extended lactation or no dry period (Grainger et al. 2009; Van Hoeij et al. 2017) or compromised udder health of cows with no dry period (Van Hoeij et al. 2016; Kok et al. 2021). Future studies, including not only dietary measures but possibly also breeding strategies could contribute to further improvement of the health and performance of cows with different VWPs or dry period lengths.

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