ABSTRACT

Purpose: My objective was to provide a critical analysis of the major nutrition variables when feeding dairy calves and to provide practical applications.

Sources: Peer-reviewed scientific literature, research abstracts, and field experiences in dairy and calf ranch operations were used.

Synthesis: A variety of liquids are fed to dairy calves in the United States, and most often, they are fed in combinations. It is critical to know and measure composition and solids levels, and to ensure consistency in what liquid is fed and how it is fed. Avoid greater than 15% solids to minimize digestive upsets due to osmolality. Traditional early weaning programs and 20% CP/20% fat milk replacer (MR) have been replaced with higher CP MR and fed at higher levels resulting in more ADG prior to weaning. Given the inverse relationship between MR fed (and its fat level) and calf starter (CS) intake, the challenge then is to moderate MR feeding early enough prior to weaning to ensure adequate CS intake prior to weaning to optimize functional rumen development and minimize postweaning slump.

Conclusions and Applications: Feed a well-texturized CS to optimize functional rumen development and avoid needing to feed forage or roughage prior to weaning. Too much forage fed too soon impairs rumen development and confounds true BW gain with gut fill. Water is the most essential nutrient needed in the greatest quantity by dairy calves. It is consumed at about 4:1 relative to DMI. Ensure water and CS containers are physically separated to avoid contamination of each in the other and to have better intake and performance. In colder weather, feed warm water. Calves are most efficient in converting nutrients to growth on a dairy farm when properly fed and managed.

Key words: calf, feeding, nutrition, milk replacer, starter

INTRODUCTION

Many variables affect dairy calf performance. Variable performance is endemic with calves and heifers, especially when the number of calves per treatment is low (Kertz and Chester-Jones, 2004). This perspective will focus on the major feeding and nutrition variables. Those are primarily liquid feeding composition and level, calf starter (CS) composition and feeding level, forage feeding, water, their interactions, and their influence on functional rumen development (Kertz 2019).

MILK OR MILK REPLACER FEEDING

Liquids Fed

Because calves are nonfunctional ruminants when born, they must be fed a liquid diet initially. In nature, that is provided by the dam’s milk. But because that milk is typically sold by commercial dairy farm operations, its use when fed to calves has historically been minimized. Cornell researchers in 1923 developed a program to feed whole milk to calves for only one month, followed by a gruel (CS) to conserve milk and wean calves early (Kertz et al., 2017). That was the advent of the early-weaning calf program. As dairy operations became larger in the United States, it became more common that transition milk (produced after initial colostrum has been secreted) and hospital or waste milk were comingle and began to be fed to calves. It is generally recommended that such waste milk be pasteurized before being fed to calves. Milk replacers (MR) are fed on many herds, but, as noted in the 2014 NAHMS data (Table 1), dairy farms feed a variety of liquid sources to calves, which varies by herd size.

Waste Milk

There are 2 major variables in the liquid sources outlined in Table 1: composition and quantity available. This is best exemplified in waste milk, which varies in quantity available on a dairy and in its composition. The composition of transition milk varies from somewhat similar to colostrum to regular milk over 5 milkings post-colostrum secretion (Foley and Otterby, 1978). Thus, the amount
and which post-colostrum milkings go into the waste milk pool greatly affect waste milk composition. Likewise, the source of hospital milk, such as from mastitic cows, affects the waste milk composition. This composition variability was illustrated in a field study from 31 dairy farms fed pasteurized waste milk (Jorgensen et al., 2006; Table 2). When I once noted the very low SCC on a large dairy farm, the manager commented that he wanted that low SCC, because it meant he had fewer mastitic cows and less waste milk to feed to his calves, sold more milk, and bought more MR. Pasteurization of waste milk is recommended to minimize pathogens, and its economics have been evaluated (Jamaluddin et al., 1996; Godden et al., 2005).

**Milk Replacers**

The main factors in MR composition are protein (CP) and fat. What has often been referred to as the “industry standard” of 20% CP and 20% fat in a MR was not a standard but a practice that evolved mainly via marketing (Kertz and Loften 2013). Furthermore, the percentages of solids and fat have important effects on digestive upsets and intake. As the percentage of solids increases above 15%, odds for digestive upsets increase due to osmolality, which then considerably exceeds that of milk. If calves are only fed MR twice daily at 15% solids, and more than 0.75 kg DM MR intake is desired, it is best to institute a third feeding, so as not to exceed 15% solids MR. Somewhat related to this aspect is that calves like consistency in feed and feeding practices. Hill et al. (2009) found that blending MR with whole milk or MR fed alone to pre-weaning calves resulted in less CS intake, and varying amount MR fed versus a constant feeding level resulted in lower ADG.

**Fat Percentage in Milk Replacer**

The percentage of fat in MR negatively affects CS and can negatively affect ADG as well. In a Minnesota study (Kuehn et al., 1994), calves were fed either 15.6 or 21.6% fat MR (Table 2). Greater MR fat at 21% versus 15% resulted in less CS intake and weight gain before weaning, with some carry-over for the 2 wk after weaning (Table 3). That is why the 2 wk after weaning are always critical to measure for carry-over effects from before full weaning. Greater CS intake on the MR treatment with 15.6% fat more than compensated for the reduced-ME MR intake on this treatment. The overall effect was 7% more ME intake on the low-fat MR treatment. This similar level (7%) of higher ME intake continued from the CS alone even after calves had been weaned for 14 d. Thus, the greater ME intake from the high-fat MR was more than compensated with reduced ME intake from CS, resulting in less total energy intake compared with the lower-fat MR treatment. This effect is often unrecognized when high-fat MR are recommended or fed. Higher-fat MR are beneficial in colder weather, especially if calves are younger than 3 to 4 wk.

**Table 1. Different liquid feeding programs used by US dairy farmers by percent of operations for number of cows per farm, as found in NAHMS (2014) survey**

<table>
<thead>
<tr>
<th>Percent of operations</th>
<th>Small (&lt;100)</th>
<th>Medium (100–500)</th>
<th>Large (&gt;500)</th>
<th>All</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nonmed MR¹</td>
<td>25.4</td>
<td>20.0</td>
<td>24.3</td>
<td>16.4</td>
</tr>
<tr>
<td>Medicated MR</td>
<td>55.1</td>
<td>49.2</td>
<td>33.5</td>
<td>37.6</td>
</tr>
<tr>
<td>Unpasteurized milk</td>
<td>67.0</td>
<td>44.2</td>
<td>26.3</td>
<td>55.7</td>
</tr>
<tr>
<td>Pasteurized milk</td>
<td>3.3</td>
<td>9.9</td>
<td>28.7</td>
<td>7.4</td>
</tr>
<tr>
<td>Milk + MR</td>
<td>10.9</td>
<td>18.9</td>
<td>20.2</td>
<td>14.4</td>
</tr>
<tr>
<td>Other</td>
<td>3.1</td>
<td>0.3</td>
<td>1.4</td>
<td>1.4</td>
</tr>
</tbody>
</table>

¹ Nonmed MR = nonmedicated milk replacer (MR).

**Table 2. Nutrient composition of pasteurized waste milk from 31 commercial dairies or custom calf rearing operations (Jorgensen et al., 2006)**

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Mean</th>
<th>Minimum</th>
<th>Maximum</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fat, % of DM</td>
<td>31.2</td>
<td>22.3</td>
<td>37.6</td>
<td>4.26</td>
</tr>
<tr>
<td>Fat, %</td>
<td>3.90</td>
<td>2.79</td>
<td>4.70</td>
<td>0.53</td>
</tr>
<tr>
<td>Protein, % of DM</td>
<td>28.1</td>
<td>23.1</td>
<td>40.8</td>
<td>3.49</td>
</tr>
<tr>
<td>Protein, %</td>
<td>3.51</td>
<td>2.89</td>
<td>5.30</td>
<td>5.10</td>
</tr>
<tr>
<td>Lactose, % of DM</td>
<td>35.3</td>
<td>30.2</td>
<td>38.4</td>
<td>1.63</td>
</tr>
<tr>
<td>Lactose, %</td>
<td>4.42</td>
<td>3.78</td>
<td>4.80</td>
<td>0.20</td>
</tr>
</tbody>
</table>
when CS intake is lower. However, CS intake still needs to be fostered for rumen development. When CS ferments in the rumen, it produces heat, which helps meet increased energy needs during colder weather. This is why wild ruminants and dairy cattle do better in colder weather versus hotter weather.

**Intensive Milk Replacer Feeding**

Following the early-weaning program established by Cornell in 1932 resulted in limited MR fed, more CS consumed, and low ADG (Kertz et al., 1979) when calves were weaned at 1 mo of age. This program changed in the early 2000s with studies at Cornell (Diaz et al., 2001; Tikofsky et al., 2001), Illinois (Blome et al., 2003; Bartlett et al., 2006), Michigan State (Brown et al., 2005; Davis Rincker et al., 2011), and New Hampshire (Cowles et al., 2006) Universities. In these programs, MR CP percentages were about 28% rather than 20%, and more than the typical 454 g daily MR DM intake was fed. The combination of greater CP percentage and more MR fed increased ADG to ~1 kg or more.

**Traditional Versus Intensive Milk Replacer Feeding**

A direct comparison of a more traditional 20% CP MR versus a 28% “intensive or accelerated” MR (Stamey et al., 2012) is shown in Figure 1. In this study, female and male Holstein calves were fed twice daily either a conventional 20% CP/20% fat MR with 12.5% solids at 10% of birth weight in 2 feedings from wk 1 to 5 and at 5% once daily during wk 6; or 28% CP/15% fat MR with 15% solids at 1.5% of BW as DM during wk 1, 2% of BW as DM during wk 2 to 5, and 5% of BW during wk 6 in 1 daily feeding. All calves were weaned at the end of 6 wk. Feeding less 20% CP/20% fat MR resulted in greater CS intake (P < 0.02) but less ADG and height increase (P < 0.02) than 28% CP/15% fat treatments during pre-weaning. Total MR intakes were 19.3 kg for 20% CP/20% fat and 34.7 kg for 28% CP/15% fat, with CS intakes before weaning of 14.0 and 7.3 kg, respectively. With greater DMI from MR, DMI of CS was reduced on 28% CP/15% fat MR, but total nutrient intake was greater on 28% CP/15% fat, resulting in greater ADG except for wk 7, which was just after full weaning. At the end of 8 wk, birth BW was approximately doubled on the 28% CP/15% fat MR treatment, but was about 10 kg less on the 20% CP/20% fat MR treatment.

From 2007 to 2014, liquid feeding in the United States increased from 3.78 to 5.68 L daily, and weaning age increased from 8 to 9 wk (NAHMS 2014).

**CALF STARTERS**

**Inverse Relationship with Milk Replacer Intake**

It is evident from the early-weaning program review (Kertz et al., 1979) and the Stamey et al. (2012) study that there is an inverse relationship between amount of milk or MR fed and CS intake. This was more clearly established in a meta-analysis by Gelsinger et al. (2016). In an analysis of 9 published studies with 21 treatments, this inverse relationship was quantified: for each 100 g DM more milk or MR intake, starter intake was decreased by 60 g.

**Intakes Before and After Weaning**

Because of low CS intakes during the first several weeks, some may recommend not feeding starter at all during the initial week of life. However, as shown in Figure 1, it was evident that on both treatments, starter intake approximately doubled from the previous week. If CS is not fed in the first several weeks, the intake curve will shift further to the right and result in less total CS intake before full weaning, less CS intake after full weaning, and most likely a slump in ADG, as noted by Urie et al. (2018a,b). The major reason for such a slump after weaning (Table 4) is most likely inadequate CS intake before weaning and inadequate rumen development by the time of weaning. Limited data on Jersey calves did not show the same pattern as data for Holsteins.
Several studies have shown that high MR feeding levels negatively affect CS intake and performance after weaning (Hill et al., 2016a,b). Calves fed about 1 kg of DM from MR before weaning had lower DMI, ADG, and digestibilities after weaning than lower feeding levels of MR. Authors concluded that 0.75 kg of daily DM from MR was approximately optimal, without negative effects after weaning. These negative effects after weaning were attributed to low CS intake and lack of functional rumen development—even with well-texturized CS used in these studies.

Forage Interactions

A classic study (Stobo et al., 1966) found reduced ADG and increased gut fill when calves were fed diets on various treatments after weaning with concentrate fixed at 0.45, 0.91, 1.36, 1.82, or 2.25 kg daily, with corresponding free-choice hay intakes being 61, 31, 25, 16, and 4% of total DMI. Daily gain increased to ~0.60 kg somewhat linearly, along with corresponding rumen papillae development, as concentrate intake increased. This ADG occurred at 16 and 4% hay in total DMI. However, results were confounded as gut contents increased with increasing hay intakes. Thus, the best ADG and rumen papillae development and least gut fill occurred with the highest concentrate and lowest hay intakes. Unfortunately, more recent CS studies in which hay is fed often do not measure gut fill and implicitly assume there is no difference or that such a difference is immaterial (Coverdale et al., 2004). That is not a safe assumption.

Calf Rumen Development

Cornell researchers in the 1950s, led by R. G. Warner, found that it is the VFA produced in the rumen that lead to rumen papillae development and the function of a calf’s rumen (Warner et al., 1956; Flatt et al., 1958; Sander et al., 1959; Harrison et al., 1960), rather than the provision of dietary forage per se, as VFA in the order of butyric, propionic, and then acetic acid lead to rumen papillae development—nearly the opposite order of that produced by ruminal forage and fiber fermentation. Unfortunately, not many understand or recognize these data today. However, there then needed to be some way to avoid marginal ruminal acidosis in young calves fed high-grain CS with no dietary forage.

Texturized Versus Pelleted

In a study conducted in the early 1970s, Porter et al. (2007) fed a CS in either all pelleted or a texturized form (pelleted with 69% cracked corn and crushed oats). These CS were formulated with 2 levels of fiber and 2 physical forms of meal versus texturized. Although there were some differences due to fiber level, the greatest differences were due to physical form of the CS. Texturized versus pelleted CS increased DMI, ADG, age when ruminating began, percent time ruminating, rumen pH, papillae length, and digestibilities of DM, NDF, and ADF. This is because the larger particles in a well-texturized CS cause the calf to regurgitate these larger particles into its mouth for chewing to reduce particle size, which also causes salivation. When these mouth contents are swallowed, the saliva buffers the rumen to keep it from becoming more acidic. This raises the question, “What is a properly texturized starter?” That study contained particle size data for reference, as did another study (Hill et al., 2008) that found negative effects for calves when including hay in a well-texturized starter. In a further study (Bateman et al., 2009), negative effects were found for fines or small particles on CS intake and ADG. There are also extensive data on CS particle size distributions, along with ingredient and nutrient compositions, in a report of 5 calf trials (Bateman et al., 2009). In general, more than 45% of the formulation needs to come from corn, oats, or barley, which can be whole (except for barley), rolled, or cracked. If the corn is quite hard and flinty, this makes it more indigestible even if cracked (Du et al., 2021). A meta-analysis of studies of physical form of CS with or without forage (Ghaffari and Kertz, 2021) found few studies with complete data on particle size, but it appears that greater CS intake occurred when hay was supplemented to the finely ground CS or when calves received texturized CS compared with pelleted diets. With either texturized or pelleted CS, pellet integrity (lack of fines) is critical because fines will decrease the intake (Bateman et al., 2009) of both of these types of CS.

Forage Fed with Calf Starters

If a pelleted CS is fed, it also needs to be fed with some forage to avoid marginal rumen acidosis. However, even low amounts of forage fed can result in gut fill. A study (Khan et al., 2011) illustrating this fed calves a CS described as “texturized” alone or with hay. The CS had “14% flatted barley, 13% flatted oats, and 10% steamed

### Table 4. Extracted from NAHMS 2018—reported calf data before and after weaning (Urie et al., 2018a,b)

<table>
<thead>
<tr>
<th>Item</th>
<th>Holsteins n = 2,273</th>
<th>Jerseys n = 114</th>
</tr>
</thead>
<tbody>
<tr>
<td>Birth weight, kg</td>
<td>43.0</td>
<td>35.1</td>
</tr>
<tr>
<td>Weaning weight, kg</td>
<td>91.4</td>
<td>70.1</td>
</tr>
<tr>
<td>Daily gain, kg</td>
<td>0.73</td>
<td>0.51</td>
</tr>
<tr>
<td>90-d weight, kg</td>
<td>104.0</td>
<td>86.2</td>
</tr>
<tr>
<td>Daily gain after weaning, kg</td>
<td>0.60</td>
<td>0.76</td>
</tr>
<tr>
<td>Birth hip height, cm</td>
<td>82.8</td>
<td>75.7</td>
</tr>
<tr>
<td>Weaning hip height, cm</td>
<td>95.3</td>
<td>85.6</td>
</tr>
<tr>
<td>Cm/d</td>
<td>0.18</td>
<td>0.145</td>
</tr>
<tr>
<td>90-d hip height, cm</td>
<td>98.0</td>
<td>89.9</td>
</tr>
<tr>
<td>Cm/mo</td>
<td>5.11</td>
<td>4.75</td>
</tr>
</tbody>
</table>
corn,” which summed to 37% processed grains. Except for barley, it is not usually necessary to process grains for a texturized starter. However, the low rumen pH of 5.06 (Table 5) clearly showed that the treatment using CS alone was not adequately texturized. Because BW was not different between the 2 treatments, true BW was distorted by 4.7 kg more gut fill (0.32 kg of which could also have been from the increased tissue weight) on the CS with hay treatment. This gut fill may not likely be visually evident. Thus, calf trials in which hay is or is not fed, as in that trial, should have gut fill measurements, to avoid confounded growth data.

### WATER

Water is the most essential nutrient needed in the greatest quantity by dairy calves. Yet it is often ignored or marginalized. It is consumed at about 4 times DMI (Kertz et al., 1984), as is also true for heifers and cows. There needs to be adequate separation between water and starter containers so calves do not drop water into starter and vice versa, as that reduces intake of both (Table 6). Water should also be kept fresh and uncontaminated, and should be analyzed for mineral content to avoid issues such as high sulfates.

Water needs to be provided to encourage calves to eat CS earlier. Waiting until 17 d after birth to begin feeding water to calves (Wickramasinghe et al., 2019) did not have major effects on CS intake and performance, most likely due to high milk feeding levels (6 to 9 L daily) and subsequent lower CS intake. However, post-weaning at 50 to 70 d, calves had greater hip height, body length, ADF and NDF digestibilities, and feed efficiency when feeding water began immediately after birth. At 5 mo of age, calves fed water immediately after birth had 13.2 kg more BW than those with a delayed start of water feeding.

When feeding higher-CP MR and at solids levels greater than 15%, water intake is even more critical. This is most likely due to greater osmotic effects (Kertz and Loften 2013). Guindon et al. (2015) found that water intake increased 1.6 times when calves were fed up to 1.1 kg DM of MR daily compared with calves fed 0.44 kg DM of MR daily. In another study (Chapman et al., 2017) water intake did not differ among treatments but when calves began weaning at wk 6, more water was consumed among treatments during wk 7 and 8 compared with the pre-weaning week.

Another dimension is that calves like warm water, especially in colder weather. In one study (Dracy and Kurtenbach, 1968), ~1 h was needed for the rumen temperature of calves to return to near normal following a 6.6°C drop after calves drank 8°C water. Drinking water of 17.2, 27.2, and 37.2°C temperatures produced progressively lesser rumen temperature drops, but it still required ~1 h for rumen temperatures to return to near normal. Another benefit of warm water feeding is that during colder weather, calves would not need to use additional dietary or body energy to warm colder water to rumen temperature. A third daily water feeding, if MR is fed only twice daily, can help increase CS intake, and its subsequent heat of rumen fermentation can help calves to keep warmer.

### APPLICATIONS AND RECOMMENDATIONS

Calves are the most efficient animals on a dairy farm in converting nutrients to growth when properly fed and managed (Bach et al., 2021).

#### Liquid Feeding

Know the nutrient composition and monitor solids level of liquid being fed. Avoid over 15% solids. Maintain consistency in what is fed and when it is fed. Feed a minimum of 6 L per calf daily in 2 feedings. If more liquid is fed, feed more than twice daily, and stage weaning over several weeks to increase CS intake before weaning.

#### Calf Starter Feeding

Feed small amounts of CS beginning immediately after completion of colostrum and transition milk feeding. Feed low levels of CS initially because CS intake approximately doubles each week. Feed a well-texturized CS and ensure that intake over 2 to 3 wk before weaning averages about 1 kg daily to avoid or minimize post-weaning slump.
Forage Feeding

There is no need to feed forage before weaning if a well-texturized CS is being fed. If all pelleted CS is being fed, feed ~3% chopped forage or roughage before weaning. For the month after weaning, feed up to ~3 kg of CS along with limited feeding daily per calf of 0.5 kg of chopped forage.

Water

Provide fresh, clean water daily beginning after feeding of colostrum and transition milk. Ensure water and CS containers are physically separated to avoid contamination of each in the other, and for optimal intake and performance. In winter, feed warm water.

Data

Measure at least periodic birth weights, CS intakes by week, and BW at weaning and at the end of the post-weaning month, to monitor and manage dairy calf feeding programs and results. The Dairy Calf and Heifer Association gold standard is to double a calf’s birth weight by the end of 2 mo of age. After weaning, calves and heifers should average ~0.8 to 0.9 kg ADG until first calving at 24 mo of age.

ACKNOWLEDGMENTS

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LITERATURE CITED


Kertz: Perspectives on dairy calf feeding and performance


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