Feed sorting in dairy cattle: Causes, consequences, and management¹

E. K. Miller-Cushon*² and T. J. DeVries†²

*Department of Animal Sciences, University of Florida, 2250 Shealy Drive, Gainesville 32601

†Department of Animal Biosciences, University of Guelph, 50 Stone Rd. East, Guelph, ON, N1G 2W1, Canada

ABSTRACT

Dairy cattle commonly sort total mixed rations, a behavior that influences individual nutrient intake and reduces the nutritive value of the ration left in the bunk across the day. Typical patterns of feed sorting in lactating dairy cows, against longer forage particles, result in greater intake of highly-fermentable carbohydrates and lesser intake of effective fiber than intended, and are associated with reduced rumen pH and altered milk composition. To understand the reason for this behavior and reduce it on-farm, numerous studies have explored the influences of ration characteristics, feeding strategies, and management factors on the expression of feed sorting. In mature cows and young calves, feed sorting is influenced by forage inclusion rate, particle size, and dry matter content. Feeding strategies that increase the time available to manipulate feed—including decreased feeding frequency and increased feeding level—may result in increased feed sorting. The extent of feed sorting is also influenced by a variety of herd-level factors, but variability between individuals in the extent of feed sorting suggests that this behavior may be subject to additional factors, including previous experience and internal state. The development of feed sorting in young calves has been explored in several recent studies, suggesting that early opportunities to sort feed, as provided by access to mixed diets, may encourage the early onset of this behavior and help it persist beyond weaning. Evidence also supports the role of feedback mechanisms that influence this behavior at the individual level. In calves and adult cows, selective consumption of higher-energy ration components may be linked to energy demands, as influenced by the availability of supplemental feed or changing metabolic status. Further, considerable evidence suggests that cattle

will adjust patterns of feed sorting in favor of physically effective fiber to attenuate low rumen pH, providing evidence for the role of postingestive feedback in feed sorting. In general, as long as cattle are provided with mixed diets that satisfy the average nutrient requirements of the group, feed sorting needs to be reduced, either through direct management or by discouraging the early development of the behavior. However, feed sorting may be functional in some scenarios, and continued research is needed to understand the feedback mechanisms that influence feed selection and sorting in young calves, replacement heifers, and mature cows. **Key words:** feed sorting, feeding behavior, dairy cow, dairy calf

INTRODUCTION

It is common in the dairy industry for lactating dairy cows to be provided a TMR, with the aim of providing the balanced nutrients needed to maintain a stable and efficient microbial population (Coppock, 1977). However, the propensity of dairy cows to select (sort) within their ration and alter their nutrient intake remains an ongoing practical challenge on-farm. Ruminants are capable of selectively consuming certain portions of plants (Methu et al., 2001), and this ability extends to the consumption of a TMR. Sorting behavior, typically against longer forage particles and in favor of smaller particles, has been reported numerous times (Leonardi and Armentano, 2003; Leonardi et al., 2005a; Miller-Cushon and DeVries, 2009); it results in an unbalanced intake of nutrients and reduces the nutritive value of the ration found in the bunk across the day (DeVries et al., 2005). Feed sorting is typically addressed by attempting to thwart sorting at the herd level, through nutrition and feeding management. However, dairy cattle vary in both the degree and pattern of feed sorting (Leonardi and Armentano, 2003), and research over the past several years has also addressed factors that may influence feed sorting at the individual level, including previous experience (Miller-Cushon et al., 2013a) and rumen health (DeVries et al., 2008). Despite an abundance of literature that addresses feed sorting from several different angles, to our knowledge

Received September 11, 2016.

Accepted October 20, 2016.

¹Presented as part of the ADSA Southern Section Symposium: Strategies for Managing Heifers in the Southeast at the ADSA-ASAS Joint Annual Meeting, Salt Lake City, Utah, July 2016.

²Corresponding authors: emillerc@ufl.edu and tdevries@uoguelph.ca

no attempt has been made to summarize the available research on this topic. In this review, we first outline the significance of feed sorting for production and health outcomes. Second, we discuss the influence of common feeding and management factors on feed sorting in calves, heifers, and cows. Third, we summarize the current state of knowledge regarding the development of feed sorting behavior in young calves. Last, we describe evidence for internal factors that may drive or provide feedback for dietary selection patterns.

IMPLICATIONS FOR HEALTH AND PRODUCTION

Feed sorting may be problematic if it leads to consumption of a diet that is different from what was formulated and delivered. Mature dairy cows have been shown to sort for the smaller feed components of their TMR, discriminating against longer forage components (Leonardi and Armentano, 2003; DeVries et al., 2007). Sorting of a TMR can mean that the ration cows actually consume is much higher in fermentable carbohydrates than intended, and much lower in effective fiber. This, in turn, may increase the risk of depressed rumen pH and SARA. In support of that hypothesis, DeVries et al. (2008) demonstrated associations between sorting and various measures of rumen pH. For example, they noted an association between sorting of long ration particles [i.e., particles >19 mm screen of the Penn State Particle Separator (**PSPS**); Kononoff et al., 2003] and maximum rumen pH ($R^2 = 0.46$): those cows selecting most against long particles had the lowest maximum rumen pH (DeVries et al., 2008). The same authors also reported that increased sorting for particle fractions that were higher in starch and lower in NDF was associated with reduced ruminal pH variables (DeVries et al., 2008). More recently, Gao and Oba (2014) demonstrated similar associations: cows that were tolerant of a high-grain diet sorted their diet to a lesser degree than cows susceptible to the high-grain diet. Susceptible cows experienced more severe SARA and sorted their diet against long particles. This pattern of sorting has been associated with lower milk fat percentage in 2 studies (DeVries et al., 2011; Fish and DeVries, 2012), likely as a result of imbalances in intake of highly fermentable carbohydrates and effective fiber, leading to SARA. In both studies, milk fat decreased by 0.15 percentage points for every 10% refusal of long forage particles in the ration. More recently, Miller-Cushon and DeVries (2015) found a similar association, with milk fat increasing by 0.1 percentage points for every 10% selection in favor of long ration particles.

Imbalanced nutrient intake and altered rumen fermentation as a result of sorting, can affect digestion

efficiency and production. In support of this, a cross-section study of commercial herds feeding TMR found that efficiency of milk production (calculated as milk yield divided by average DMI) decreased by 3% for every 1 percentage point of group-level selective overconsumption (sorting) of fine ration particles [particles <1.18 screen of the PSPS; Sova et al. (2013)]. Sorting of a TMR can also reduce the nutritive value of what remains in the feed bunk, particularly in the later hours after feed delivery (DeVries et al., 2005; Hosseinkhani et al., 2008). For group-fed cattle, this may have a negative effect on cows that do not have access to feed when it is delivered. For example, high competition at the feed bunk may restrict subordinate, primiparous, or compromised (e.g., lame) animals to feeding later in the day, and these cattle may end up consuming a ration that is different from that formulated for their production and growth requirements. This, in turn, may affect production targets; for example, diets that are higher in NDF and lower in energy can restrict DMI and reduce milk yield (Rabelo et al., 2003). Sova et al. (2013) demonstrated that every group-level increase of 2 percentage points in selection against long ration particles was associated with a per-cow reduction of 0.9 kg/d of 4% FCM. Imbalances in nutrient intake relative to that predicted may also limit cows' ability to optimize milk components; for example, Miller-Cushon and DeVries (2015) reported that milk protein content decreased by 0.05% for every 10% refusal of long ration particles.

Feed sorting may also affect the time course of feed consumption. Greter and DeVries (2011) associated greater sorting against long ration particles with a slower rate of feed consumption ($R^2 = 0.57$). It is noteworthy that the same researchers could also explain ~25% of the variability in DMI by cow feed sorting patterns. In particular, reduced DMI was associated with more sorting against long particles ($r^2 = 0.23$) and with more sorting for short ration particles ($r^2 = 0.26$). Thus, in situations where cattle devote much time to sorting their feed, they may also be limiting their ability to maximize their DMI.

It must be noted, however, that these effects of feed sorting are not always consistent. For example, DeVries et al. (2011) demonstrated that, in cows in a period of peak lactation to peak DMI, greater selection against longer ration particles was associated with greater efficiency of milk production. This result could be explained by the fact that across cows, very little sorting of long ration particles (<10% refusal) was observed in that study. Further, given increasing DMI and decreasing milk yield over the study observation period, any refusal of long particles would correspond to less

effective fiber intake and could improve feed conversion efficiency (Yang and Beauchemin, 2006a).

When considering the effects of feed sorting, it is also important to consider the resulting effects on total intake of dietary nutrients. For example, Maulfair et al. (2010) demonstrated that feed sorting (of dietary particles, NDF, and starch) varied considerably between diets containing grass hay of different particle lengths, but the actual intake of those dietary components was similar across the day, resulting in no effect on rumen fermentation and no difference in production parameters. On the other hand, feed sorting can also help cattle achieve the required levels of nutrient intake. For example, Greter et al. (2008) demonstrated that prepubescent heifers fed diets diluted with straw that limited DMI sorted against the long particles and for the shorter particles, so that their actual nutrient intakes matched that required for their targeted level of growth.

CONTROL OF FEED SORTING

Given the negative effects of feed sorting on the nutrient composition of the ration consumed and potential detrimental effects for production, feed sorting is addressed primarily at the group level by implementing nutritional, feeding management, and housing strategies to reduce sorting. Although feed sorting is typically associated with adult animals provided a TMR, calves are also capable of sorting a mixed diet from early in life. Preweaned calves can sort diets consisting of chopped hay and concentrate (observed in wk 6 of life; Miller-Cushon et al., 2013a) and pelleted diets (observed first in wk 4 of life; Miller-Cushon et al., 2014b), suggesting that feed sorting is a behavior that requires consideration whenever mixed diets are presented to young calves. The provision of mixed diets to preweaned and recently weaned calves is not common practice in North America, but several recent studies have evaluated the importance of these types of diets for the performance of heifers (DeVries and von Keyserlingk, 2009; Greter et al., 2010) and younger calves (Groen et al., 2015; Overvest et al., 2016). Here, we discuss ration characteristics and management factors that influence the extent of feed sorting in calves, weaned heifers, and mature cows.

Ration Characteristics That Influence Feed Sorting

Feed sorting is greatly subject to ration characteristics, including forage inclusion rate, particle size, and DM content. Increasing forage inclusion rate increases sorting against the forage component in both calves

and adult cows. Weaned calves provided a dry TMR (texturized concentrate and chopped straw) sorted against long particles to a greater extent when straw inclusion level was higher (30% straw vs. 15% straw; Groen et al., 2015). Similar results were observed when straw was added (by 10 and 20%) to a silage-based TMR fed to prepubescent heifers (Greter et al., 2008). The opposite effect has been observed in lactating cow rations, however. DeVries et al. (2007, 2008) found that lactating dairy cows actually demonstrated less sorting against longer forage particles and for smaller particles when fed diets that were higher in forage content ($\geq 60\%$ forage DM) compared with diets that were lower in forage content ($\leq 50\%$ forage DM). The difference in this response was likely related to the types and particle size of the forages in those lactating cow rations, as well as their moisture content.

Leonardi and Armentano (2003) found that increasing the amount of chopped alfalfa hay from 20 to 40% in a dry TMR ($>69\%$ DM), while reducing the amount of alfalfa silage, increased sorting against the forage particles. It is presumable that dry forage particles are much more easily sorted than fermented forage particles. In support of this, Overvest et al. (2016) found that recently weaned dairy calves provided a silage-based TMR (51% DM) did not sort for or against any particular size fraction, whereas calves provided a dry mixed diet of chopped hay and concentrate sorted in favor of shorter particles.

Forage particle size is also likely to influence ease of sorting and preference for the forage component. Montoro et al. (2013) reported that calves selected in favor of the concentrate component before weaning when provided a mixed diet containing hay that was finely ground instead of coarsely chopped, suggesting that the calves preferred physically effective ration particles. In lactating cows, selection for small particles was increased by including long alfalfa hay (rather than chopped) in the ration (Leonardi and Armentano, 2003). Similarly, Onetti et al. (2004) found that decreasing the particle size of alfalfa hay increased NDF intake, indicating that cows were not able to sort as well with shorter particle sizes. Similar effects have been observed when altering silage particle size. Leonardi et al. (2005b) reported that cows decreased their sorting behavior when fed diets with oat silage of reduced particle size. Kononoff and Heinrichs (2003) reported less sorting against long particles in a TMR with corn silage of reduced particle length. Zebeli et al. (2008) reported similar effects from reducing the particle length of corn silage, observing less sorting for fine particles; the authors related this reduction in sorting to a decrease in the proportion of ruminal propionate and an increase in the ratio of acetate to propionate.

Altering ration DM content has been explored in several studies as a potential means of reducing feed sorting, based on the assumption that water addition will help bind small particles to large particles, making it more difficult for cows to consume selectively. Leonardi et al. (2005a) added water to a dry TMR (to reduce dietary DM from 80.8 to 64.4%) and found that water addition reduced sorting against long particles and tended to result in increased NDF intake and greater milk fat percentage (3.31 vs. 3.41%). Similarly, Fish and DeVries (2012) found that adding water to a TMR to reduce dietary DM from 62 to 52% resulted in less sorting for the smallest ration particles. It should be noted, however, that rations typically provided to high-production dairy herds are typically wetter (40 to 60% DM; Eastridge, 2006) than those given in these studies. Two other studies investigated the effects of water addition to a TMR containing only haylage and corn silage forage sources (Miller-Cushon and DeVries, 2009; Felton and DeVries, 2010). Miller-Cushon and DeVries (2009) reduced TMR DM content from 58 to 48% by adding water. Similarly, Felton and DeVries (2010) reduced TMR DM content from 56 to 50 to 44%. In both studies, the addition of water to these higher-moisture TMR containing no dry forage actually resulted in more feed sorting. Furthermore, in both studies, higher amounts of added water resulted in lower DMI, potentially due, in part, to the filling effect of higher-moisture rations. Interestingly, Felton and DeVries (2010) reported that when greater amounts of water were added to the TMR, feed temperature increased to a larger extent in the hours after the feed was placed in the feed bunk, particularly during times of higher ambient temperatures. They suggested that this increased temperature may have been indicative of feed spoilage and may have also contributed to the observed increase in feed sorting.

Liquid feed supplements, particularly molasses-based supplements, have also been evaluated as a way to reduce feed sorting. Oelker et al. (2009) found that using a molasses-based liquid feed reduced sorting of a diet based on corn silage. Similarly, DeVries and Gill (2012) reported that the addition of a molasses-based liquid feed supplement to a TMR (51% DM) altered the particle size distribution by reducing the number of short particles, and the extent of sorting against longest ration particles. Interestingly, in cattle provided high-grain diets, sorting in favor of small forage components can also be prevented by adding molasses-based liquid feed (Gordon and DeVries, 2016). However, Eastridge et al. (2011) found that addition of liquid feed to a dry dairy cow ration (>64% DM) did not effectively reduce feed sorting.

In general, the effects of ration particle size, forage type (dry vs. wet), and dietary DM content on feed sorting are likely related to ease of sorting; separation of forage particles from grain components occurs more easily when particle size is distinct and the ration (or its forage components) is relatively dry. However, more research is required to determine the optimal forage particle size to restrict feed sorting, while still maintaining physical effectiveness within the diet. It would also be beneficial to conduct research to determine how dietary factors (i.e., forage type, forage particle size, DM content) interact, so that findings can be generalized to many different diets observed in commercial situations. Researchers have recently begun to evaluate the ration characteristics that influence feed sorting in younger animals, but our knowledge in this area is lacking, particularly in postweaned heifers. Further work could investigate whether ration characteristics that influence sorting in adult cows also influence sorting in growing replacement heifers.

Management Factors That Influence Feed Sorting

Management factors and feeding environment may also influence the degree of feed sorting. Both the time available and total amount of feed provided have a large effect on how much a TMR will be sorted. It stands to reason that the more time cows have available with a given amount of TMR, the more they will be able to sort. As such, the frequency by which TMR is delivered daily has an effect on feed sorting; in particular, providing feed more than once per day (1×) has been shown to reduce feed sorting. In 2 controlled pen-level studies by DeVries et al. (2005), feed sorting (as measured by changes in NDF content of the feed in the bunk over the course of the day) was compared for cows fed 1× to twice per day (2×), and 2× to 4 times per day, respectively. They found that the NDF content of feed in the bunk increased to a greater degree across the day for cows fed 1× compared with cows fed 2×; theorts contained 8% more forage when cows were fed 1×. However, the authors observed no differences in sorting when comparing feed delivery of 2× to 4×. More recently, Hart et al. (2014) compared feeding 1×, 2×, and 3× in a cow-level study; they compared predicted and actual intakes of various PSPS particle fractions of the diet. In that study, when cows were fed 3×, they did not sort for or against fine particles, but they did sort against those particles when fed 1× or 2×. The small effect of feed delivery frequency in that study may have been the result of the diet fed, because little to no sorting of the entire ration took place, with ≤2% selection for or against any of the PSPS particle fractions. The

effects of feed delivery frequency on feed sorting have also been noted in observational studies of commercial dairy herds. In a cross-sectional study by Endres and Espejo (2010) of 50 herds in Minnesota, each visited once, herds fed once per day had a greater change in ration NDF content across the day compared with those fed 2× to 3×. In another cross-sectional study by Sova et al. (2013) of 22 herds in Ontario, Canada, feed sorting was estimated for 7 consecutive days on each farm, both in summer and winter, by comparing actual pen-level intakes of various PSPS particle fractions to that predicted. Those researchers noted a tendency for a decrease in sorting against long particles in herds fed 2×; this result was consistent regardless of season.

In addition to the time available to sort feed, the amount of feed provided may also influence the level of feed sorting. In a study by Leonardi and Armentano (2007), a wide range of feed refusals was noted (6 to 33% of feed offered), and this was negatively associated ($r = -0.57$) with the sorting of the longest ration particles. This finding was supported by Miller-Cushon and DeVries (2010), who found a linear association between the level of feeding (i.e., proportion of Orts, ranging from 3 to 20% of feed offered) and the amount of sorting for medium-length particles ($R^2 = 0.49$) and against short particles ($R^2 = 0.48$). This association of feeding level and sorting has also been observed at the herd level; Sova et al. (2013) found that each increase of 2 percentage points in refusal rate (ranging from 1 to 9%) was associated with a 1.3% increase in group-level selective refusal of long particles and 0.6 and 0.5% increases in group-level selective consumption of short and fine particles, respectively. Together, these results indicate that feeding for a low refusal amount without limiting DMI may promote consumption of a diet close to that intended. Given that the NDF content of the remaining feed in the bunk increases throughout the day with feed sorting (DeVries et al., 2005), feeding for a low refusal amount may influence animals in a group differently, with some accessing the diet and sorting extensively, and others consuming a previously sorted diet. However, this strategy does appear to be beneficial overall: Sova et al. (2013) reported that lower refusal amounts were associated with lesser sorting against long particles, and that lesser group-level selection against long particles was associated with greater milk yield.

It is also possible that the physical feeding environment plays a role in the ability of dairy cattle to sort their feed and the extent to which they do it. The simple presence of conspecifics may increase the amount of sorting individual cows engage in. For example, Leonardi and Armentano (2007) reported that the extent of feed sorting (against longer particles and for shorter

particles) was greater in a group freestall setting than among cows individually fed in a tiestall setting. More research is needed to corroborate that finding, and determine the motivating factors for increased sorting in a group environment. To do that, methods for measuring sorting in individual animals that are fed in a group from a common feed source, need to be developed and validated.

One potential motivating factor for increased sorting in a group-feeding situation may be social pressure. If that were the case, then increasing social pressure by increasing competition for feed access could enhance the amount of sorting. Unfortunately, no data support that idea. Hosseinkhani et al. (2008) studied the effect of competition for feed access (2 vs. 1 cow per feeding bin) and reported no effect on the amount of feed sorting. However, despite competition's lack of effect on the degree of feed sorting, it can indirectly increase the variability in feed consumption associated with feed sorting. As demonstrated by Hosseinkhani et al. (2008), competition for feed access may force some cows to shift their intake patterns, such that they will consume more feed during the later hours after feed delivery, after much of the feed sorting has already occurred.

The area in which feed is placed for access by dairy cattle may also influence the ability of cattle to sort. Sorting could be more easily accomplished in a flat feed bunk as opposed to a more enclosed type bunk/manger (e.g., J bunk), because cows would have more ability to push feed around and away on a flat bunk surface. However, no empirical data are available to support this hypothesis; further research is needed in this area.

DEVELOPMENT OF FEED SORTING

It has been well established that the feeding behavior of ruminants is subject to early feed experiences. For example, lambs develop persistent preferences for particular plants to which they have been exposed early in life (Squibb et al., 1990). Factors influencing the broader development of dairy calf feeding behavior have been reviewed recently by Miller-Cushon and DeVries (2015). In recent years, several studies have explored the influences of early feed experiences, including feed exposure and feed presentation, on the development of feed sorting in young calves.

Dairy calves exposed to either hay or concentrate during the milk-feeding stage sorted a mixed diet (60% forage and 40% concentrate, DM basis) in favor of the familiar feed component shortly after weaning (Miller-Cushon and DeVries, 2011), indicating that previous feed experience may have a carryover effect on feed sorting, at least for a short period. Within 4 wk of common experience with the mixed diet, calves in that

study exhibited a similar pattern of sorting for concentrate and against hay, regardless of their feed exposure in the milk-feeding stage (Miller-Cushon and DeVries, 2011). To our knowledge, no other studies to date have evaluated the potential for early-life experiences to have persistent effects on preference for different ration components and patterns of feed sorting. For ration components that differ considerably in nutrient composition, as with forage and grain, it may be likely that dietary experience would eventually override previous experience. Short-term influences of previous feed exposure on feed preferences and feed sorting may be driven by both an established preference for familiar feed types and a short-lived period of neophobia, because young ruminants often consume only small amounts when initially presented with an unfamiliar feed (Squibb et al., 1990). Food neophobia in young calves is influenced by social housing, and calves raised with other calves and cows have lower latencies before they begin consuming a variety of novel foods (Costa et al., 2014). The interaction between social housing and the development of feed sorting has yet to be explored, and could be an interesting area for future research.

Whereas no evidence to date shows that early experiences have a prolonged effect on the feed preferences of dairy calves, previous feed experiences do influence the extent of postweaning sorting, although results vary across studies. The expression of feed sorting during the preweaning stage is subject to several feed factors, including feed presentation (Miller-Cushon et al., 2013a) and ration forage particle size (Montoro et al., 2013), and the opportunity to sort early in life appears to have a carryover effect on the degree of sorting in the postweaning period. Sorting behavior during the milk-feeding stage persisted postweaning in a 2-part study described by Montoro et al. (2013) and Miller-Cushon et al. (2013b). Before weaning, sorting behavior in the milk-feeding stage was influenced by ration forage particle size: calves selected for hay when it was coarsely chopped and sorted for starter when the hay was finely ground (Montoro et al., 2013). Postweaning, calves on that trial were all offered the mixed diet containing the coarsely chopped hay (90% crumb starter concentrate and 10% chopped hay), and sorting behavior was monitored for 3 wk (Miller-Cushon et al., 2013b). Calves previously offered the mixed diet containing finely ground hay maintained sorting in favor of the concentrate component in the postweaning period, but calves that had been previously offered the diet containing coarsely chopped hay did not sort in favor of either component. In another study, calves previously provided a mixed diet (30% chopped hay and 70% concentrate) rather than separate feed components during the milk-feeding stage also did not sort to a greater

extent postweaning, when all calves were provided the same mixed diet (Miller-Cushon et al., 2013a). When sorting was measured at 2 wk and 4 wk postweaning, calves with previous exposure to the mixed diet overconsumed NFC and underconsumed NDF, changes in nutrient composition consistent with selection in favor of the grain component and against the hay component in their diet. In contrast, calves given hay and concentrate separately during the milk-feeding stage did not sort for or against those feed components. Interestingly, differences in the extent of feed sorting persisted at 6 wk postweaning and were maintained through transition to a novel haylage-based TMR. Although none of the feed components of this TMR were familiar, the pattern of sorting for longer particles and against grain particles persisted in calves that had been raised with the mixed diet, whereas calves raised with separate feed components continued not to sort their diet. This finding suggests that sorting patterns and abilities, once learned, may persist despite ration changes. In general, results from these studies suggest that the learning and postweaning persistence of feed sorting may depend on the opportunity to exercise this behavior early in life. In contrast, Overvest et al. (2016) found that all calves offered a mixed diet after weaning (85% concentrate, 15% chopped hay) sorted their diet similarly, regardless of whether they had been offered the mixed diet, hay, and concentrate separately, or only concentrate during the preweaning period. Inconsistencies in findings between these studies are difficult to explain, although approaches to measuring feed sorting did vary between studies; Miller-Cushon et al. (2013a) and Montoro et al. (2013) used complete nutrient analysis of offered and refused feed as an indicator of selection between forage and concentrate components, whereas Overvest et al. (2016) used particle-size analysis, which may not have fully distinguished between ration ingredients (chopped forage and concentrate). Continued work is needed to better understand the role of early experience in the development of feed sorting behavior. Furthermore, no studies to date have attempted to monitor differences in feed sorting arising from early experience for a longer period than 6 to 8 wk postweaning; longer-term studies would add to our knowledge in this area.

In general, we can assume that feed sorting will develop when calves are first given a diet that they are physically capable of sorting (i.e., a diet consisting of a mixture of components that can be separated) and motivated to sort (i.e., a diet that differs in composition from the ratio of components they would self-select). Regardless of ration composition, we might expect that the motivation to sort will be present, at least for some animals, given that feed preferences and nutrient requirements vary between individuals and, especially in

growing calves, are unlikely to be static over time. Efforts to discourage the development of feed sorting may then rely on preventing feed sorting with some of the feed management approaches (ration characteristics, liquid feed additives) discussed in the previous section.

In addition to experiences influencing the young calf, previous experience may affect the extent of feed sorting in older animals. Greter et al. (2010) evaluated the effects of previous exposure to different feed presentations (mixed diet or forage top-dressed with concentrate) on feed sorting in heifers at approximately 8 mo of age after transition to a novel TMR. Although feed presentation influenced selection for concentrate, there was no difference in the extent of feed sorting once all heifers received the TMR, in contrast to the effects of feed presentations on the extent of later feed sorting in younger calves (Miller-Cushon et al., 2013a). Similarly, Groen et al. (2015) found that, although sorting behavior in weaned bull calves (about 3 mo of age) was influenced by dietary treatments differing in forage inclusion rate, the pattern of sorting was similar across animals once they were transitioned to a TMR. These results suggest that, in older animals with previous experience of feed sorting, the extent of sorting is more likely to depend on the physical and chemical characteristics of the ration than on previously expressed patterns of sorting. However, dairy cattle undergo several dietary transitions at different stages of growth and lactation, and previous experience may have at least short-lived effects on behavior at those transitions. In heifers, the method of transition to a novel TMR has been found to influence the extent of sorting of that ration (Miller-Cushon et al., 2015). In this study, heifers were either transitioned to the TMR directly or exposed to the ration components, offered separately (haylage, corn silage, high-moisture corn, and a pelleted protein supplement), for 8 d before receiving the TMR. Heifers offered the separate components sorted haylage and corn silage extensively, and then sorted the TMR against long particles and for short and fine particles to a greater extent than heifers transitioned directly to the novel TMR. We encourage further work evaluating feed sorting at the time of dietary transition, to assess whether recent previous experiences or the method of transition to a novel diet may influence feed sorting.

FEEDBACK AND FUNCTION OF FEED SORTING

Diet selection, in general, is often discussed in terms of optimal foraging theory, which predicts that foraging decisions should favor food types that are most profitable in terms of energy yield per unit of time required to ingest it (Hughes, 1993). This theory is supported by

some observations that grazing choices seem to maximize energy intake on a time scale, whether over a day (Wallis de Vries and Daleboudt, 1994) or within a feeding bout (Fortin et al., 2002). This foraging strategy should be adaptive to many environments, but it is not supported in all situations. For example, in domestic ruminants offered readily accessible and highly digestible feeds, feed characteristics other than energy content influence selection. Sheep offered both concentrate and long forage will consume considerable amounts of forage, even though it requires more time and energy to chew and digest and is less nutrient-dense (Forbes and Kyriazakis, 1995). Application of optimal diet theory to dietary selection in ruminants, therefore, requires consideration of constraints, such as prevention of excess intake of rapidly fermentable carbohydrate, which is associated with a rapid rise in rumen concentration of VFA and potential disruption of normal rumen fermentation (Forbes and Kyriazakis, 1995).

In the sorting of mixed diets by dairy cattle, the typical pattern of selecting for higher-energy particles that may be ingested more rapidly would be expected under optimal foraging theory. However, this behavior varies between and within individuals. Leonardi and Armeniano (2003) reported that the extent of feed sorting varied considerably between individual animals subject to the same management factors. More generally, individual variability in diet selection is also evident in several studies that have provided cattle of different ages with free access to different feed types. Webb et al. (2014) noted a wide range of feed preferences in calves offered free access to milk replacer, concentrate, and a range of forages. Several studies have explored the effects of offering component diets to cattle, instead of mixed rations. For example, Moya et al. (2011) described feeding behavior of cattle offered different free-choice diets and reported that preferences for certain feed ingredients depended on the other dietary components provided. Similarly, Devant et al. (2015) found that dietary selection in component-fed heifers depended on the dietary components and feed form. In both studies, the proportion of dietary components consumed changed over time.

Variability in feed sorting between individuals and over time suggests that this behavior is motivated by a range of internal factors. Here, we discuss evidence for several of these, including perceived palatability of feed ingredients and physiological changes. Importantly, Provenza and Balph (1987) suggest that learning about feeds is an essential component of foraging optimally, and differences in learning could explain individual differences in selection. In cases where cattle can learn about feeds, forming associations between particular

feed ingredients and postingestive feedback, feed sorting is likely to adapt to changing internal conditions and may have a functional outcome for the animal.

Coppock (1977) claimed that the advantages of providing a TMR to dairy cattle included the ability to mask the flavor of unpalatable ration ingredients, reducing the likelihood that changes in ration formulation would reduce intake. However, the palatability of individual ration components is likely a major factor driving feeding sorting. The most commonly reported direction of feed sorting—cattle sorting for smaller grain particles and against longer forage components—is consistent with a preference for sweet flavors (Nombekela et al., 1994). In younger animals, evaluation of preferences for specific flavors has been less explored, but preferences for specific feed components are clearly present in calves, even before weaning. In a series of pairwise preference tests, calves were found to prefer certain feed components commonly included in starter rations, including soybean meal and wheat meal, whereas others, such as corn gluten meal and rapeseed meal, were much less preferred (Miller-Cushon et al., 2014a). Rejection of some of these feed ingredients may be attributed to aversive flavors, such as the bitter flavor of glucosinolates in rapeseed meal (Lardy and Kerley, 1994), but factors driving preferences for others are not always obvious. Overall preferences for certain feed types are evident, but preferences vary by individual (Miller-Cushon et al., 2014a; Webb et al., 2014). Regardless, it is clear that cattle of all ages possess preferences for certain flavors and feed types. We can assume that some of these preferences are innate, rather than subject to previous experience and learning, because clear feed preferences are apparent in previously inexperienced calves (Miller-Cushon et al., 2014a). Therefore, feed sorting in many cases may be considered hedonically rewarding. It follows that deviations from this typical direction of feed sorting at the individual level may be due to other constraints or feedback mechanisms.

Feed preference tests can help us understand what ration components an animal may select preferentially, but preference in an experimental setting is a measure of what an animal chooses when minimal physical constraints are present (Rutter, 2006). In contrast, feed sorting requires that a cow search through her diet to select for a particular ration component, and preference can be modified by the circumstances in which feed is provided (Rutter, 2006). Thus, preferences for feed ingredients presented in pairwise tests may not always translate to corresponding feed sorting patterns.

Feed sorting is also likely to depend on feedback mechanisms. The ability of animals to form associations between the sensory properties of feed and postingestive

feedback and then adjust dietary selection has been well documented, and those learned associations are often considered to play a primary role in the perceived palatability, or hedonic value, of a food source (Provenza, 1995). The ability to apply such learning leads to animals avoiding foods associated with malaise, potentially arising from toxins or nutrient imbalances, and is often referred to as “nutritional wisdom.” For example, ruminants will avoid foods associated with induced illness (Burritt and Provenza, 1989). Lambs offered high-protein and low-protein diets were able to select a diet providing optimal amounts of protein for growth (Kyriazakis and Oldham, 1993). Given sufficient experience with different diets, it may be expected that feed preferences, and therefore dietary selection or feed sorting, are influenced by postingestive feedback mechanisms to some extent. Several studies have shed some light on this question in young calves, as well as in adult cows.

In young calves, evidence to suggest that calves are particularly adept at balancing a diet based on specific nutrient requirements during the milk-feeding stage is limited. Montoro and Bach (2012) provided calves free access to 6 separate feed ingredients, varying in nutrient composition, and compared their performance to calves provided a single mash starter feed containing the same 6 ingredients. Although total intake and growth did not differ between treatments, calves offered the free-choice diet consumed a diet higher in protein and fat than that in the formulated control diet, which was designed to meet their growth requirements. These authors concluded that calves were unable to balance their nutrient requirements by consuming varying proportions of offered feed ingredients. Similarly, Miller-Cushon et al. (2014b) evaluated the influence of protein source on dietary selection and feed sorting of calves offered pelleted diets, and found that protein intake depended greatly on palatability factors. Calves in that study were offered free choice of a base low-protein starter pellet (12% CP) and a high-protein pellet (40% CP) containing either soybean meal (which is preferred in pairwise preference tests, and so considered to be highly palatable; Miller-Cushon et al., 2014a) or canola meal (which is not preferred by calves). Dietary CP intake was lower in calves offered the protein pellet formulated with canola meal. Further, when calves were offered a single pelleted starter containing the high-protein ingredient to which they had previously been exposed, total intake was reduced when the starter contained canola meal. In a second experiment, Miller-Cushon et al. (2014b) offered calves a choice of 2 mixed pelleted diets during the milk-feeding stage: one contained the low-protein base starter pellet and the high-protein soybean meal pellet, and the other contained the low-

protein base starter pellet and the high-protein canola meal pellet (70% base starter pellet, and 30% high-protein pellet). Calves exhibited a preference for the mixed diet containing the soybean pellet and, further, sorted within the soybean pellet mixture for protein and sorted within the canola meal pellet mixture against protein. These results suggested that feed sorting and dietary selection were subject to innate feed preferences, given that calves had prolonged exposure to the diets and did not alter selection. Thus, milk-fed calves may not be sensitive to protein imbalances in their diet. It may not be surprising if feed preferences in young calves are primarily subject to sensory properties and innate preference, given that low solid feed intake in conjunction with milk intake may confuse the association of solid feed properties with postingestive feedback (Duncan and Young, 2002). In support of this, the feed intake of young calves is affected by changes in the sensory properties of the feed in the absence of changes to nutrient content and, consequently, postingestive feedback; for example, solid feed intake in young calves has been increased by adding the same flavor additive to solid feed and milk (Morrill and Dayton, 1978).

Innate preferences for certain flavors and feed types appear to have a considerable influence on dietary selection and feed sorting in young calves, but selection between forage and grain components of a mixed diet may also be subject to some degree of postingestive feedback. Two recent studies have reported that feed sorting is influenced by the availability of supplemental feed. Miller-Cushon et al. (2013a) found that calves provided a mixed diet (70% grain and 30% chopped hay) selected in favor of hay during the milk-feeding stage, when they were receiving 8 L/d of milk replacer, but selected in favor of grain after weaning. These results suggested that increased selection in favor of the higher-energy grain component may have been influenced by an increased reliance on solid feed for energy following removal of milk. The influence of supplemental feed on feed sorting was also evaluated by Costa et al. (2016), in young calves offered access to a TMR (containing roughly 51% silage and dry hay and 49% concentrate) and calf starter from birth. These authors reported that, at 10 d after weaning, calves selected in favor of the long forage particles in the TMR and against the small particles. However, this direction of sorting changed on the day after removal of the supplemental calf starter, with calves sorting in favor of the fine particles of the TMR. Results from both of these studies suggest that the sorting behavior of young calves may depend on the availability of other nutrient sources. As described by Costa et al. (2016), changes in forage selection patterns in response to other feed sources may depend on a combination of factors, including nutritional requirements,

rumen function, or motivation to chew and ruminate. It has been established that hay intake can increase rumen pH (Khan et al., 2011) and rumination time (Castells et al., 2012). Further, access to hay reduces non-nutritive oral behaviors, including licking surfaces, tongue rolling, and consuming bedding (Castells et al., 2012; Montoro et al., 2013). Based on these results, it could be speculated that calves are capable of forming an association between consumption of hay and postingestive feedback stemming from changing rumen environment; we encourage further research to explore this question.

Whereas the relationship between feed sorting and rumen health in calves is only speculative, it is well established that mature cattle are capable of modifying feed sorting behavior in direct response to changes in the rumen environment. Keunen et al. (2002) demonstrated that when cows were induced with SARA and given a choice between long alfalfa hay and alfalfa pellets, they increased their preference for the alfalfa hay. Kmicikewycz and Heinrichs (2014) similarly demonstrated that SARA-induced cows had a greater preference for high-quality long orchardgrass hay, rather than chopped hay, during their recovery. Not only will cows choose to consume a more physically effective fiber source during acidosis, they will sort a TMR for long particles when fed diets that cause low ruminal pH (Beauchemin and Yang, 2005; Yang and Beauchemin, 2006b). DeVries et al. (2008) also induced acidosis in lactating dairy cows and found that cows altered their sorting behavior of a TMR to select in favor of long forage particles, rather than against such particles as they typically would. Interestingly, these researchers also provided evidence to suggest that the severity of acidosis and repeated experience influenced the extent to which lactating dairy cows will sort their TMR to attenuate low ruminal pH. More recently, Maulfair et al. (2013) and Kmicikewycz and Heinrichs (2015) similarly demonstrated that cows will alter their feed preferences for more physically effective forage particles during an induced bout of SARA. Similarly, beef cattle, fed a high-grain, low-forage, feedlot diet will increase their sorting for the forage component of their diet upon experience of a bout of acidosis (DeVries et al., 2014a), and the degree to which they increase their sorting is directly related to the degree of acidosis (DeVries et al., 2014b). All of these studies indicate that cattle may exhibit “nutritional wisdom” in response to altered rumen environments. From a practical standpoint, this means that obvious changes in the diet selection patterns of dairy cows in a herd may indicate that they are experiencing some disruption to normal rumen function.

Alterations in feed sorting by mature dairy cows may not only be limited to disrupted rumen function.

DeVries et al. (2011) studied how sorting changes as cows transition from peak production to peak DMI. At peak production (corresponding to measurements taken at 53 DIM), all cows exhibited greater sorting against ADF and for CP in their ration. In addition to having the greatest production at that time, all cows were also mobilizing the greatest amount of body reserves. This suggests, then, that cows may have been sorting to maximize the digestibility of their feed (i.e., by sorting against ADF), and to maximize their nutrient intake (i.e., by sorting for CP), to minimize their energy deficit and meet the demands of lactation. More work is needed to corroborate these findings, and to more broadly identify how changing physiological demands (associated with lactation, growth, and pregnancy) may influence the dietary selection of dairy cows.

CONCLUSIONS

Understanding factors that influence feed sorting is important from a management standpoint, because this behavior negatively affects health and production of dairy cattle. Ration characteristics, feeding strategies, and management factors influence the expression of feed sorting in young calves, growing heifers, and mature cows. Early feeding strategies influence the emergence of this behavior in young calves, and some research suggests a potential for carryover effects of previous feed experiences. Further research is needed to better understand how previous experience may influence feed sorting, both in young calves and through dietary transitions in older animals, and for how long behavioral differences arising from early experience may persist. Feed sorting appears to be frequently driven by an innate preference for smaller, nutrient-dense grain particles, but alterations in the pattern of feed sorting in response to changing energy demands and rumen environment suggest that feed sorting is subject to postingestive feedback mechanisms. Continued research is needed to better understand the motivation and control of feed sorting, and to explore the extent to which this behavior may have functional outcomes for the individual animal.

ACKNOWLEDGMENTS

Much of the research reviewed in this paper was funded in part by Natural Sciences and Engineering Research Council of Canada (NSERC; Ottawa, ON, Canada), Discovery grants awarded to T. J. DeVries, and Ontario Ministry of Agriculture Food and Rural Affairs/University of Guelph Production Systems research grants. Other project support came from NSERC Collaborative Research and Development grants and

Engage grants, as well as from industry support from Liquid Feeds International Ltd. (Innerkip, ON, Canada) and Nutreco Canada Inc. (Guelph, ON, Canada).

REFERENCES

- Beauchemin, K. A., and W. Z. Yang. 2005. Effects of physically effective fiber on intake, chewing activity, and ruminal acidosis for dairy cows fed diets based on corn silage. *J. Dairy Sci.* 88:2117–2129.
- Burritt, E. A., and F. D. Provenza. 1989. Food aversion learning: Ability of lambs to distinguish safe from harmful foods. *J. Anim. Sci.* 67:1732–1739.
- Castells, L., A. Bach, G. Araujo, C. Montoro, and M. Terré. 2012. Effect of different forage sources on performance and feeding behavior of Holstein calves. *J. Dairy Sci.* 95:286–293.
- Coppock, C. E. 1977. Feeding methods and grouping systems. *J. Dairy Sci.* 60:1327–1336.
- Costa, J. H. C., N. A. Adderley, D. M. Weary, and M. A. G. von Keyserlingk. 2016. Short communication: Effect of diet changes on sorting behavior of weaned dairy calves. *J. Dairy Sci.* 99:5635–5639.
- Costa, J. H. C., R. Daros, M. A. G. von Keyserlingk, and D. M. Weary. 2014. Complex social housing reduces food neophobia in dairy calves. *J. Dairy Sci.* 97:7804–7810.
- Devant, M., B. Quintana, A. Aris, and A. Bach. 2015. Fattening Holstein heifers by feeding high-moisture corn (whole or ground) ad libitum separately from concentrate and straw. *J. Anim. Sci.* 93:4903–4916.
- DeVries, T. J., K. A. Beauchemin, and M. A. G. von Keyserlingk. 2007. Dietary forage concentration affects the feed sorting behavior of lactating dairy cows. *J. Dairy Sci.* 90:5572–5579.
- DeVries, T. J., F. Dohme, and K. A. Beauchemin. 2008. Repeated ruminal acidosis challenges in lactating dairy cows at high and low risk for developing acidosis: Feed sorting. *J. Dairy Sci.* 91:3958–3967.
- DeVries, T. J., and R. M. Gill. 2012. Adding liquid feed to a total mixed ration reduces feed sorting behavior and improves productivity of lactating dairy cows. *J. Dairy Sci.* 95:2648–2655.
- DeVries, T. J., L. Holtshausen, M. Oba, and K. A. Beauchemin. 2011. Effect of parity and stage of lactation on feed sorting behavior of lactating dairy cows. *J. Dairy Sci.* 94:4039–4045.
- DeVries, T. J., T. Schwaiger, K. A. Beauchemin, and G. B. Penner. 2014a. The duration of time that beef cattle are fed a high-grain diet affects feed sorting behavior, both prior to and after acute ruminal acidosis. *J. Anim. Sci.* 92:1728–1737.
- DeVries, T. J., T. Schwaiger, K. A. Beauchemin, and G. B. Penner. 2014b. Impact of severity of ruminal acidosis on feed sorting behaviour of beef cattle. *Anim. Prod. Sci.* 54:1238–1242.
- DeVries, T. J., and M. A. G. von Keyserlingk. 2009. Short communication: Feeding method affects the feeding behavior of growing dairy heifers. *J. Dairy Sci.* 92:1161–1168.
- DeVries, T. J., M. A. G. von Keyserlingk, and K. A. Beauchemin. 2005. Frequency of feed delivery affects the behavior of lactating dairy cows. *J. Dairy Sci.* 88:3553–3562.
- Duncan, A. J., and S. A. Young. 2002. Can goats learn about foods through conditioned food aversions and preferences when multiple food options are simultaneously available? *J. Anim. Sci.* 80:2091–2098.
- Eastridge, M. L. 2006. Major advances in applied dairy cattle nutrition. *J. Dairy Sci.* 89:1311–1323.
- Eastridge, M. L., A. H. Lefeld, A. M. Eilenfeld, P. N. Gott, W. S. Bowen, and J. L. Firkins. 2011. Corn grain and liquid feed as nonfiber carbohydrate sources in diets for lactating dairy cows. *J. Dairy Sci.* 94:3045–3053.
- Endres, M. I., and L. A. Espejo. 2010. Feeding management and characteristics of rations for high-producing dairy cows in freestall herds. *J. Dairy Sci.* 93:822–829.
- Felton, C. A., and T. J. DeVries. 2010. Effect of water addition to a total mixed ration on feed temperature, feed intake, sorting behavior, and milk production of dairy cows. *J. Dairy Sci.* 93:2651–2660.

- Fish, J. A., and T. J. DeVries. 2012. Varying dietary dry matter concentration through water addition: Effect on nutrient intake and sorting of dairy cows in late lactation. *J. Dairy Sci.* 95:850–855.
- Forbes, J. M., and I. Kyriazakis. 1995. Food preferences in farm animals: Why don't they always choose wisely? *Proc. Nutr. Soc.* 54:429–440.
- Fortin, D., J. M. Fryxell, and R. Pilote. 2002. The temporal scale of foraging decisions in bison. *Ecology* 83:970–982.
- Gao, X., and M. Oba. 2014. Relationship of severity of subacute ruminal acidosis to rumen fermentation, chewing activities, sorting behavior, and milk production in lactating dairy cows fed a high-grain diet. *J. Dairy Sci.* 97:3006–3016.
- Gordon, L. J., and T. J. DeVries. 2016. Technical note: Impact of a molasses-based liquid feed supplement on the feed sorting behavior and growth of grain-fed veal calves. *J. Anim. Sci.* 94:3519–3526.
- Greter, A. M., and T. J. DeVries. 2011. Effect of feeding amount on the feeding and sorting behaviour of lactating dairy cattle. *Can. J. Anim. Sci.* 91:47–54.
- Greter, A. M., T. J. DeVries, and M. A. G. von Keyserlingk. 2008. Nutrient intake and feeding behavior of growing dairy heifers: Effects of dietary dilution. *J. Dairy Sci.* 91:2786–2795.
- Greter, A. M., K. E. Leslie, G. J. Mason, B. W. McBride, and T. J. DeVries. 2010. Effect of feed delivery method on the behavior and growth of dairy heifers. *J. Dairy Sci.* 93:1668–1676.
- Groen, M. J., M. A. Steele, and T. J. DeVries. 2015. Short communication: Effect of straw inclusion rate in a dry total mixed ration on the behavior of weaned dairy calves. *J. Dairy Sci.* 98:2693–2700.
- Hart, K. D., B. W. McBride, T. F. Duffield, and T. J. DeVries. 2014. Effect of frequency of feed delivery on the behavior and productivity of lactating dairy cows. *J. Dairy Sci.* 97:1713–1724.
- Hosseinkhani, A., T. J. DeVries, K. L. Proudfoot, R. Valizadeh, D. M. Veira, and M. A. G. von Keyserlingk. 2008. The effects of feed bunk competition on the feed sorting behavior of close-up dry cows. *J. Dairy Sci.* 91:1115–1121.
- Hughes, R. N. 1993. *Diet Selection: An Interdisciplinary Approach to Foraging Behaviour*. Blackwell Scientific Publications, Cambridge, MA.
- Keunen, J. E., J. C. Plaizier, L. Kyriazakis, T. F. Duffield, T. M. Widowski, M. I. Lindinger, and B. W. McBride. 2002. Effects of a subacute ruminal acidosis model on the diet selection of dairy cows. *J. Dairy Sci.* 85:3304–3313.
- Khan, M. A., D. M. Weary, and M. A. G. von Keyserlingk. 2011. Hay intake improves performance and rumen development of calves fed higher quantities of milk. *J. Dairy Sci.* 94:3547–3553.
- Kmicikewycz, A. D., and A. J. Heinrichs. 2014. Feeding lactating dairy cattle long hay separate from the total mixed ration can maintain dry matter intake during incidents of low rumen pH. *J. Dairy Sci.* 97:7175–7184.
- Kmicikewycz, A. D., and A. J. Heinrichs. 2015. Effect of corn silage particle size and supplemental hay on rumen pH and feed preference by dairy cows fed high-starch diets. *J. Dairy Sci.* 98:373–385.
- Kononoff, P. J., and A. J. Heinrichs. 2003. The effect of corn silage particle size and cottonseed hulls on cows in early lactation. *J. Dairy Sci.* 86:2438–2451.
- Kononoff, P. J., A. J. Heinrichs, and D. A. Buckmaster. 2003. Modification of the Penn State forage and total mixed ration particle separator and the effects of moisture content on its measurements. *J. Dairy Sci.* 86:1858–1863.
- Kyriazakis, I., and J. D. Oldham. 1993. Diet selection in sheep: the ability of growing lambs to select a diet that meets their crude protein (nitrogen $\times$ 6.25) requirements. *Br. J. Nutr.* 69:617–629.
- Lardy, G. P., and M. S. Kerley. 1994. Effect of increasing the dietary level of rapeseed meal on intake by growing beef steers. *J. Anim. Sci.* 72:1936–1942.
- Leonardi, C., and L. E. Armentano. 2003. Effect of quantity, quality, and length of alfalfa hay on selective consumption by dairy cows. *J. Dairy Sci.* 86:557–564.
- Leonardi, C., and L. E. Armentano. 2007. Feed selection by dairy cows fed individually in a tie-stall or as a group in a free-stall barn. *J. Dairy Sci.* 90:2386–2389.
- Leonardi, C., F. Giannico, and L. E. Armentano. 2005a. Effect of water addition on selective consumption (sorting) of dry diets by dairy cattle. *J. Dairy Sci.* 88:1043–1049.
- Leonardi, C., K. J. Shinnars, and L. E. Armentano. 2005b. Effects of different dietary geometric mean particle length and particle size distribution of oat silage on feeding behavior and productivity performance of dairy cattle. *J. Dairy Sci.* 88:698–710.
- Maulfair, D. D., K. K. McIntyre, and A. J. Heinrichs. 2013. Subacute rumen acidosis and total mixed ration preference in lactating dairy cows. *J. Dairy Sci.* 96:6610–6620.
- Maulfair, D. D., G. I. Zanton, M. Fustini, and A. J. Heinrichs. 2010. Effect of feed sorting on chewing behavior, production, and rumen fermentation in lactating dairy cows. *J. Dairy Sci.* 93:4791–4803.
- Methu, J. N., E. Owen, A. L. Abate, and J. C. Tanner. 2001. Botanical and nutritional composition of maize stover, intakes and feed selection by dairy cattle. *Livest. Prod. Sci.* 71:87–96.
- Miller-Cushon, E. K., R. Bergeron, K. E. Leslie, G. J. Mason, and T. J. DeVries. 2013a. Effect of early exposure to different feed presentations on feed sorting of dairy calves. *J. Dairy Sci.* 96:4624–4633.
- Miller-Cushon, E. K., and T. J. DeVries. 2009. Effect of dietary dry matter concentration on the sorting behavior of lactating dairy cows fed a total mixed ration. *J. Dairy Sci.* 92:3292–3298.
- Miller-Cushon, E. K., and T. J. DeVries. 2010. Feeding amount affects the sorting behavior of lactating dairy cows. *Can. J. Anim. Sci.* 90:1–7.
- Miller-Cushon, E. K., and T. J. DeVries. 2011. Effect of early feed type exposure on diet-selection behavior of dairy calves. *J. Dairy Sci.* 94:342–350.
- Miller-Cushon, E. K., and T. J. DeVries. 2015. Associations between feed push-up frequency, lying and feeding behavior, and milk composition of dairy cows. *J. Dairy Sci.* 98(E-Suppl. 2):13. (Abstr.)
- Miller-Cushon, E. K., C. Montoro, A. Bach, and T. J. DeVries. 2013b. Effect of early exposure to mixed rations differing in forage particle size on feed sorting of dairy calves. *J. Dairy Sci.* 96:3257–3264.
- Miller-Cushon, E. K., C. Montoro, I. R. Ipharraguerre, and A. Bach. 2014a. Dietary preference in dairy calves for feed ingredients high in energy and protein. *J. Dairy Sci.* 97:1634–1644.
- Miller-Cushon, E. K., M. Terré, T. J. DeVries, and A. Bach. 2014b. The effect of palatability of protein source on dietary selection in dairy calves. *J. Dairy Sci.* 97:4444–4454.
- Miller-Cushon, E. K., J. P. Vogel, and T. J. DeVries. 2015. Short communication: Feed sorting of dairy heifers is influenced by method of dietary transition. *J. Dairy Sci.* 98:2687–2692.
- Montoro, C., and A. Bach. 2012. Voluntary selection of starter feed ingredients offered separately to nursing calves. *Livest. Sci.* 149:62–69.
- Montoro, C., E. K. Miller-Cushon, T. J. DeVries, and A. Bach. 2013. Effect of physical form of forage on performance, feeding behavior, and digestibility of Holstein calves. *J. Dairy Sci.* 96:1117–1124.
- Morrill, J. L., and A. D. Dayton. 1978. Effect of feed flavor in milk and calf starter on feed consumption and growth. *J. Dairy Sci.* 61:229–232.
- Moya, D., A. Mazzenga, L. Holtshausen, G. Cozzi, L. A. Gonzalez, S. Calsamiglia, D. G. Gibb, T. A. McAllister, K. A. Beauchemin, and K. Schwartkopf-Genswein. 2011. Feeding behavior and ruminal acidosis in beef cattle offered a total mixed ration or dietary components separately. *J. Anim. Sci.* 89:520–530.
- Nombekela, S. W., M. R. Murphy, H. W. Gonyou, and J. I. Marden. 1994. Dietary preferences in early lactation cows as affected by primary tastes and some common feed flavors. *J. Dairy Sci.* 77:2393–2399.
- Oelker, E. R., C. Reveneau, and J. L. Firkins. 2009. Interaction of molasses and monensin in alfalfa hay- or corn silage-based diets on rumen fermentation, total tract digestibility, and milk production by Holstein cows. *J. Dairy Sci.* 92:270–285.
- Onetti, S. G., S. M. Reynal, and R. R. Grummer. 2004. Effect of alfalfa forage preservation method and particle length on performance of dairy cows fed corn silage-based diets and tallow. *J. Dairy Sci.* 87:652–664.
- Overvest, M. A., R. Bergeron, D. B. Haley, and T. J. DeVries. 2016. Effect of feed type and method of presentation on feeding behav-

- ior, intake, and growth of dairy calves fed a high level of milk. *J. Dairy Sci.* 99:317–327.
- Provenza, F. D. 1995. Postingestive feedback as an elementary determinant of food preference and intake in ruminants. *J. Range Manage.* 48:2–17.
- Provenza, F. D., and D. F. Balph. 1987. Diet learning by domestic ruminants: Theory, evidence and practical implications. *Appl. Anim. Behav. Sci.* 18:211–232.
- Rabelo, E., R. L. Rezende, S. J. Bertics, and R. R. Grummer. 2003. Effects of transition diets varying in dietary energy density on lactation performance and ruminal parameters of dairy cows. *J. Dairy Sci.* 86:916–925.
- Rutter, S. M. 2006. Diet preference for grass and legumes in free-ranging domestic sheep and cattle: Current theory and future application. *Appl. Anim. Behav. Sci.* 97:17–35.
- Sova, A. D., S. J. LeBlanc, B. W. McBride, and T. J. DeVries. 2013. Associations between herd-level feeding management practices, feed sorting, and milk production in freestall dairy farms. *J. Dairy Sci.* 96:4759–4770.
- Squibb, R. C., F. D. Provenza, and D. F. Balph. 1990. Effect of age of exposure on consumption of a shrub by sheep. *J. Anim. Sci.* 68:987–997.
- Wallis de Vries, M. F., and C. Daleboudt. 1994. Foraging strategy of cattle in patchy grassland. *Ecology* 100:98–106.
- Webb, L. E., B. Engel, H. Berends, C. G. van Reenen, W. J. J. Gerrits, I. J. M. de Boer, and E. A. M. Bokkers. 2014. What do calves choose to eat and how do preferences affect behavior? *Appl. Anim. Behav. Sci.* 161:7–19.
- Yang, W. Z., and K. A. Beauchemin. 2006a. Increasing the physically effective fiber content of dairy cow diets may lower efficiency of feed use. *J. Dairy Sci.* 89:2694–2704.
- Yang, W. Z., and K. A. Beauchemin. 2006b. Effects of physically effective fiber on chewing activity and ruminal pH of dairy cows fed diets based on barley silage. *J. Dairy Sci.* 89:217–228.
- Zebeli, Q., M. Tafaj, B. Junck, V. Olschlager, B. Ametaj, and W. Drockner. 2008. Evaluation of the response of ruminal fermentation and activities of nonstarch polysaccharide-degrading enzymes to particle length of corn silage in dairy cows. *J. Dairy Sci.* 91:2388–2398.