Effect of Feeding Strategy and Social Housing on Behaviour at Weaning in Dairy Calves

By

Morgan Anna Overvest

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ABSTRACT

EFFECT OF FEEDING STRATEGY AND SOCIAL HOUSING ON BEHAVIOUR AT WEANING IN DAIRY CALVES

Morgan Anna Overvest **Advisor:**
University of Guelph, 2015 **Dr. Trevor DeVries**

The objective of this dissertation was to determine the effect of an accelerated milk feeding program on time budget around weaning, with or without the influence of social housing, and the effect of various feed types and presentations on behaviour and growth of calves fed this high milk level. In the first study, calves were housed individually or in pairs until weaning, when all calves were paired. In a second study, calves were offered chopped grass hay and grain mixed, as separate components, grain only, or a silage-based total mixed ration (TMR). Calves housed in pairs consumed more feed than those housed individually. Individually-housed calves showed a decrease in lying time the day post-mixing and altered feeding behaviour in the post-weaning period. Prior to weaning, in the second study, all calves showed similar feed intake and weight gain, however, during the weaning and post-weaning phases, calves fed a silage-based TMR showed lower dry matter intake and weight gain than calves offered other feeds with higher dry matter content. In summary, calves altered time budgets to adjust for changes over the weaning period, more so when paired for the first time. Calves offered TMR could not consume enough feed on a dry matter basis, due to the high moisture content of their feed. Additionally, there were no noticeable effects of offering forage to calves on growth and overall feed intake throughout the pre-weaning and weaning period.

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LIST OF ABBREVIATIONS

ADF – acid detergent fibre
ADG – average daily gain
BHBA – beta-hydroxybutyrate
BW – body weight
CP – crude protein
DM – dry matter
DMI – dry matter intake
ME – metabolizable energy
NDF – neutral detergent fibre
NFC – non-fibre carbohydrates
PSPS – Penn State Particle Separator
TMR – total mixed ration

Treatment names

IH – calves housed individually; Chapter 2
PH – calves housed in pairs; Chapter 2
TMR – total mixed ration; Chapter 3
MIX – concentrate and chopped hay offered as a mixture in a ratio of 85:15; Chapter 3
SEP – concentrate and chopped hay offered as separate components; Chapter 3
CON – only concentrate offered; Chapter 3

CHAPTER 1: GENERAL INTRODUCTION

Calves fed high levels of milk show fewer signs of decreased welfare (De Paula Vieira et al., 2008) and higher growth rates (Appleby et al., 2001; Jasper and Weary, 2002) during the milk-feeding stage. Prior to milk weaning, calves on accelerated milk feeding programs have a nutritional advantage over calves fed traditional, restrictive amounts of milk. However, calves fed milk at higher levels experience a larger challenge during the weaning period (Terré et al., 2007). In the past, calves have been fed low levels of milk in order to decrease feed costs and promote early solid feed consumption (Kertz et al., 1979). The purpose of a low-milk feeding program is to encourage calves to consume solid feed prior to weaning, as milk offered is not sufficient for satiety (Kertz et al., 1979); however it is also not sufficient for proper nutrient and growth requirements (Drackley, 2008). Calves fed higher milk levels consume less solid feed prior to milk-weaning, and thus may have underdeveloped digestive systems at weaning when compared with restrictively-fed calves consuming greater levels of solid feed (Terré et al., 2007).

In traditional calf raising systems, calves are often raised individually during the milk weaning stage to prevent negative behaviours, such as cross-sucking (De Passille, 2001) and higher incidence of disease (Tomkins, 1991). However, social housing can improve calf welfare and increase dry matter intake (DMI) as a result of social facilitation (Chua et al., 2002), particularly at weaning time. Some dairy producers are still hesitant to implement group housing due to the belief that group housing increases spread of disease and cross-sucking behaviour (Tomkins, 1991; Van Putten, 1982). Modern systems of calf raising, especially over the milk-weaning stage, do not closely resemble how calves are raised in nature, thus studying time budgets and behaviour patterns of calves at weaning in modern systems gives insight into the effects of commercial farming systems on the well-being of dairy calves.

To develop the best weaning strategy for calves fed large volumes of milk, all aspects of weaning must be considered to sustain the growth advantage of high milk feeding levels. Therefore, this review will identify the benefits of accelerated milk feeding, investigate the benefits and detriments of different weaning procedures, analyze different strategies for providing solid feed, outline the effects of social housing, and summarize current knowledge of the time budget of dairy calves around the weaning time.

1.1 Accelerated Milk Feeding Programs

For many years, on commercial dairy farms, calves have often been offered low levels of milk, the equivalent of approximately half of the intake achieved when milk is offered ad libitum (Appleby et al., 2001). Current research has shown that this low level of milk is insufficient for the optimal growth and health of calves (Jasper and Weary, 2002). When fed via teat, calves offered an accelerated level of milk at 20% of initial body weight (BW) or greater, show higher gains than calves fed restrictively (Appleby et al., 2001; Hammon et al., 2002; Jasper and Weary, 2002). However, when calves are fed small amounts of milk, these meals are more often offered via bucket (Jasper and Weary, 2002). Bucket feeding has been shown to increase non-nutritive sucking in group housed calves when compared with calves offered milk from an artificial teat (Hammell et al., 1988). To encourage more natural drinking behaviour and to maximize calf growth, milk feeding through a teat at levels closer to ad libitum is recommended (Jasper and Weary, 2002).

Calves have been offered low levels of milk, approximately 10 % of initial birth BW, to promote greater solid feed intake at a young age (Maynard and Norris, 1923). This method of feeding has been considered common practice for many years. However, more recent research has highlighted the detriments of low milk feeding to calf growth and welfare, despite the improvement in early solid feed consumption (Jasper and Weary, 2002; Khan et al., 2007a; De Paula Vieira et al., 2008). The amount of milk consumed when offered ad libitum is much greater than that of restricted milk feeding systems, from 2.5 to 3 times the conventional intake level, or an average of 10 to 12 L per calf/d (Appleby et al., 2001; Jasper and Weary, 2002; Miller-Cushon et al., 2013a). The benefits of such accelerated milk feeding programs are extensive. Calves fed milk ad libitum are free to exhibit more natural feeding behaviour (Miller-Cushon et al., 2013a). In a natural situation, calves left to suckle their dam may consume many milk meals in the first week of life, approximately 8 to 12 meals per day (Reinhardt and Reinhardt, 1981). Each of these meals lasts an average of 10 min per bout (Reinhardt and Reinhardt, 1981). When offered limited amounts of milk via buckets, calves consume their daily meals in much less time than calves fed ad libitum via teats; calves offered milk via teats spent approximately 47 min/d drinking milk while calves drinking restricted amounts of milk from buckets had 2 meals/d lasting approximately 45 seconds each (Appleby et al., 2001). While teat feeding is also used when calves are offered less milk, it would be expected that their rate of intake would be similar to calves fed ad libitum via teat. However, the total feeding time and number of meals per day would be more similar to calves limit-fed via buckets. As teat-feeding systems slow down the rate of milk intake, it has been shown that teat-feeding improves digestion by allowing nutritive sucking and increasing digestive hormone release that contributes to feelings of satiety (de Passillé et al., 1993). If calves do not have the opportunity to suck for milk, their strong motivation to perform the behaviour will likely lead to non-nutritive sucking even in calves provided sufficient levels of milk (Hammell et al., 1988). Although mimicking natural feeding systems with high meal frequency and slower consumption via teat would be most ideal for the calf, there would be an increase in labour input to feed calves multiple times per day. Thus, the best option for calf raising that promotes the most natural feeding behaviour is an accelerated milk feeding program with milk offered via a teat system.

There is concern in the industry that calves fed high levels of milk may show a higher occurrence of diarrhea. There is some disagreement in the literature with respect to the occurrence and incidence of diarrhea when calves are fed high levels of milk; in some cases this may be confused with higher fecal score (Diaz et al., 2001). Some researchers report no change in the occurrence of diarrhea with an increase in milk allowance (Jasper and Weary, 2002; Khan et al., 2007a), while others report an increase (Quigley et al., 2006). Calves fed higher levels of milk showed higher fecal scores without signs of sickness compared to calves fed restrictively (Diaz et al., 2001), perhaps due to higher liquid excretion rate. There are also numerous factors that contribute to incidences of diarrhea that may cause this variation in results across studies, namely management factors such as cleanliness and colostrum intake and resultant calf immunity (Hammon et al., 2002; Jasper and Weary, 2002). It should be noted that if the temperature of the calf's environment falls below the thermoneutral zone, calves fed restrictive amounts of milk may not have sufficient nutrient intake to sustain growth (Drackley, 2008). Additionally, immune function is strongly associated with nutrition; therefore, if calves experience nutritional deficiency, they have a higher susceptibility for disease (Nonnecke et al., 2003). Thus calves fed restricted amount may be at higher risk of diarrhea.

Many commercial dairies continue to feed low levels of milk with the expectation that calves will consume greater amounts of concentrate, a more cost effective feedstuff, at an early age (Kertz et al., 1979). Although this theory has been widely accepted, it is flawed. Calves fed milk restrictively consume up to twice the amount of solid feed as their ad libitum counterparts, but this does not result in equal nutrient intake (Sweeney et al., 2010). When fed restrictive levels of milk, despite consuming large amounts of solid feed, calves are unable to produce similar growth rates that are reached by ad libitum fed calves (Appleby et al., 2001; Jasper and Weary, 2002; Sweeney et al., 2010). This approach not only leaves calves feeling hungry (De Paula Vieira et al., 2008) and at higher risk for disease (Nonnecke et al., 2003), but creates lost opportunity for high growth rates at a period of high growth and efficiency potential. Feeding greater amounts of milk promotes an improvement in growth rate (Jasper and Weary, 2002; Miller-Cushon et al., 2013a) and shows a positive effect on feed efficiency (Diaz et al., 2001). Long-term benefits of increased milk allowances have been demonstrated in several studies. Recently, Soberon et al. (2012) showed an increase of 1,113 kg in 305-d milk production in the first lactation for every 1 kg increase in ADG pre-weaning. Earlier research found decreased age at first calving and greater first lactation milk production in calves that had increased pre-weaning ADG as a result of being left to nurse from the dam early in life (Bar-Peled et al., 1997). Therefore, it is important to evaluate raising methods that promote high growth rates early in life.

Although calves offered greater amounts of milk consume little solid feed prior to weaning, when milk-weaning is gradual, calves fed more milk show equal or greater solid feed intake post-weaning when compared to calves fed restrictively (Jasper and Weary, 2002; Khan et al., 2007). However, when calves on high milk levels are weaned abruptly, their post-weaning solid feed intakes are too low to maintain the weight advantage over restrictively fed calves (Terré et al., 2007). Therefore, a proper weaning protocol is crucial to the success of a high-milk feeding program to sustain the growth advantage of the greater milk input past the post-weaning stage (Jasper and Weary, 2002).

1.2 Weaning Programs

In commercial dairy farm environments calves are removed from the dam in the first few days of life and then provided whole milk or milk replacer by bucket or artificial teat. Calves are weaned off of milk at approximately 6 to 8 weeks of age (Vasseur et al., 2010), abruptly or gradually (Sweeney et al., 2010), offered varying types and levels of solid feed (Castells et al., 2012) and housed individually or in groups (De Paula Vieira et al., 2010). Thus, there is large variation in application of most of these variables on dairy farms today. Opportunities exist for investigation into factors that may improve the growth and health of high milk fed calves over the weaning period.

Under natural circumstances, young ruminants develop solid feeding behaviour based on the feeding choices and behaviours of their dams (Mirza and Provenza, 1994). As the calf ages, when the dam is no longer the provider of the main component of the calf's diet, her influence on the consumption of solid feed decreases (Mirza and Provenza, 1994). When left with the dam, calves are gradually weaned off of milk at about 10 months of age (Reinhardt and Reinhardt, 1981). Although increased milk allowances in calf raising programs have begun to cater to the natural instinct of the calf, many aspects of calf raising still show little similarity to natural situations. In commercial settings, where calves have been fed low levels of milk, solid feed consumption is encouraged early on in life (Kertz et al., 1979). This is not the case in nature where calves are offered nearly unlimited access to a supply of milk from the dam and begin to mimic her grazing behaviour early in life (Key and McIver, 1980). Commercially, calves are removed from the dam shortly after birth and milk weaning occurs much before 10 months of age, between 6 and 8 weeks of age (Vasseur et al., 2010), often using methods dissimilar to what would occur in nature (Jasper et al., 2008).

Calves fed conventionally are often abruptly weaned off of milk, which tends to have negative consequences on the growth and behaviour of the calf, as increased signs of hunger and increased levels of cross-sucking have been found (Nielsen et al., 2008). When fed high levels of milk, it would be expected that calves would have greater difficulty with an abrupt weaning strategy (Sweeney et al., 2010), and therefore these calves may benefit from a gradual weaning program. In a unique study by Sweeney et al. (2010), calves were fed high levels of milk and weaned abruptly or gradually by volume over 22, 10, or 4 days. On all gradual programs calves could not compensate for the decrease in energy intake from milk with a sufficient increase in starter intake. Although calves weaned gradually over 10 days performed better than calves weaned over 22 days and 4 days, they still showed decreased weight gains during weaning. However, despite a decrease in rate of gain over the weaning period, calves weaned over 10 days did not show post-weaning weight loss as seen in abruptly weaned calves (Sweeney et al., 2010). This indicates that despite not losing weight, calves still may not grow to their full potential over the weaning period on gradual volume reduction weaning plans. Calves fed on a volume reduction program still consume more solid feed post-weaning than calves fed conventionally and abruptly weaned, indicating that a high milk level and gradual weaning program is still better for overall growth (Khan et al., 2007). An alternative option to volume reduction is gradual weaning by diluting the milk ration. Calves weaned by dilution, compared to volume reduction, consume less solid feed prior to weaning (Nielsen et al., 2008). In another study of weaning by dilution, calves weaned by dilution showed higher concentrate intakes, than calves weaned abruptly, however these calves were weaned 3 weeks later than animals in the previously mentioned study, and were better established on grain at the time of milk-weaning (Jasper et al., 2008). More research on gradual weaning methods is necessary to determine the best methods for use in high milk fed calves.

While there is a wealth of information on approximate weaning age in natural situations (Reinhardt and Reinhardt, 1981), there is a paucity of research focused on the best age of weaning for calves in commercial situations. In a study by Kehoe et al. (2007), calves fed a restrictive amount of milk showed weaning calves at wk 4, 5, or 6 had no effect on growth by wk 8; however this study concluded at wk 8 and did not compare growth of calves weaned at a later age or fed higher levels of milk. There is little research to date on effect of weaning age on growth and health in commercial dairies. Although gradual weaning is beneficial to calves fed large amounts of milk, beginning this weaning program too early can be detrimental to pre-weaning growth. Calves started on a gradual weaning program, beginning at 19 d of age and gradually reducing milk available from 12 L/d for 22 d, did not achieve the same growth rates as calves weaned gradually over 10 and 4 d (Sweeney et al., 2010). Recent work by Eckert et al. (2015) found that extending the weaning age of calves fed accelerated milk feeding programs from 6 to 8 wks increased starter intake and ADG over the weaning period. Therefore, even on accelerated milk feeding programs, beginning a weaning program too early is detrimental to growth and development.

Weaning based on starter concentrate intake is another subject of recent research. Weaning calves when concentrate intake reaches a pre-determined level is more suited to the needs of the individual calf (de Passillé and Rushen, 2012). Research suggests calves can be weaned sooner when using the concentrate intake method of weaning; however, this approach varies largely on the amount of concentrate intake set as the appropriate level for weaning (Roth et al., 2009; de Passillé and Rushen, 2012). This weaning program requires close scrutiny of concentrate intake and constant re-adjustment over the weaning period to achieve the best results. At this time, this method is not practical for on farm use, but does provide an interesting basis for future research as automation in calf feeding increases in popularity. Encouraging solid feed intake early on is a vital component of all weaning programs. The transition from pre-ruminant to functioning ruminant is a difficult transition that can be made easier when calves consume significant levels of solid feed while still provided milk (Khan et al., 2011).

1.3 Solid Feed for Young Calves

A fundamental component of all weaning programs is the type and method of presentation of solid feed offered. To transition from pre-ruminant to a functioning ruminant a calf must first consume solid feed. When the source of a calf's nutrients shift from liquid to solid feed, it is crucial that the feed offered is not only palatable, but highly digestible for the young ruminant (Drackely, 2008). It is well known that the fermentation of solid feed, specifically concentrate, to volatile fatty acids (VFAs), such as butyrate, early on, triggers the development of ruminal papillae (Tamate et al., 1962; Stobo et al., 1966). In calves offered only milk, no microbial fermentation occurs in the foregut, thus the production of ketones at this time is negligible (Baldwin et al., 2004). The presence of beta-hydroxybutyric acid (BHBA) in the blood of young calves is therefore indicative of rumen development such that BHBA is produced from butyrate by rumen epithelium (Quigley et al., 1992; Coverdale et al., 2004; Khan et al., 2011). An increase in blood BHBA with age is thought to indicate a shift from pre-ruminant to functioning ruminant (Khan et al., 2011). Quigley et al. (1992) showed calves offered hay and a maximum of 4.5 kg/d of concentrate showed decreased blood BHBA concentration with increased hay intake. However, other research without a limit on concentrate intake, shows no effect of hay on blood BHBA concentration and a rise in BHBA with increased DMI and calf age (Khan et al., 2011). Butyrate is the most stimulatory of the VFAs produced by the rumen in regards to epithelial development (Tamate et al., 1962), although over-stimulation of ruminal papillae may cause keratinization of papillae (Thompson et al., 1958). Other detriments of overfeeding carbohydrates in the young calf's diet include decreased rumen motility (Clarke and Reid, 1974) and a reduction in ruminal pH (Beharka et al., 1998). While increasing the amount of concentrate in the diet of pre-weaned calves promotes increased papillae density and height, it does not necessarily increase rumen weight and muscularity (Stobo et al., 1966).

There is disagreement in the dairy industry in regards to the feeding of forages pre-weaning. Some research discourages this practice due to the perception that it may hinder papillae development by increasing acetate production and decreasing butyrate production in the rumen (Tamate et al., 1962). A main concern of feeding forages to young ruminants is that the accumulation of forage in the rumen may hinder the intake of concentrate (Drackley, 2008). In this case, calves would consume greater amounts of forage, which is of lower energy density than concentrate. Thus, the concern is a lower overall energy intake and growth rate if forage intake displaces concentrate intake in calves pre-weaning (Kertz et al, 1979; Phillips et al., 2004). However, studies that have contributed to this idea have offered calves low levels of milk (Kertz et al, 1979; Phillips et al., 2004), whereas in newer work, where researchers have offered forage to calves fed high levels of milk, the same results are not observed (Khan et al., 2011). This is likely due to satiation of calves from milk meals and low overall solid feed intake. Thomas and Hinks (1982) first demonstrated that providing forages to young calves increased rumen pH with no effect on rumen VFA concentration. In agreement with the aforementioned study, further research has showed increased rumen pH with forage intake in both calves fed high and restrictive levels of milk with varying types of forage (Khan et al., 2011; Castells et al., 2013). In addition to the healthier rumen environment promoted by forage feeding, development of the muscular wall of the rumen is stimulated by forage feeding at a young age (Tamate et al., 1962). Greater empty rumen weight has been used as an indicator of rumen muscular development in most studies on growth and development of young calves, showing increases in rumen weight and capacity with inclusion of forages in the diet (Tamate et al., 1962; Suárez et al., 2006; Khan et al., 2011). As a consequence of increased rumen development, feeding forage has been shown to increase feed efficiency in calves fed hay and textured calf starter (Coverdale et al., 2004; Khan et al., 2011). To achieve optimal rumen development, calves must consume diets high in carbohydrates for ruminal papillae development with a source of forage available to stimulate muscular development of the rumen. If calves are fed sufficient levels of milk, forage intake does not seem to displace concentrate intake (Khan et al., 2011).

Type of forage may contribute to the effect of forage feeding on rumen development and performance in young calves. Calves fed varying types of forage pre-weaning (i.e. chopped hay or straw, corn or triticale silage) have higher DMI and growth rates than calves offered only concentrate, with the exception of calves offered chopped alfalfa hay (Castells et al., 2012). Grass forages have been shown to improve overall intake when offered in conjunction with starter feed, whereas legume forages tend to have the opposite effect (Castells et al., 2012). Castells et al. (2012) offered two types of silage to calves in addition to calf starter. In comparison, calves fed concentrate only, and calves offered corn silage showed lower ADG than calves offered triticale silage. Calves offered triticale silage also showed an early increase in overall feed intake when compared to concentrate only calves, indicating that calves were able to successfully utilize nutrients from this fermented feed source (Castells et al., 2012). There is limited literature on the use of fermented feed in dairy calf diets. Previous studies have had different approaches to analysing the type and DMI of different forage for pre-weaned calves. Suárez et al. (2007) did not report differences in overall feed intake or ADG when calves were offered varying types (straw, grass hay, and corn silage) and concentrations of forage. In previous studies (Coverdale et al., 2004; Suárez et al., 2007) calves were offered forage and concentrate in a mixed ratio, with forage accounting for anywhere from 7.5 to 60.0 % of the mixture. When calves were offered forage and concentrate separately, they consumed forage at closer to 5% of overall feed intake (Castells et al., 2012). However, a study by Miller-Cushon et al. (2013b) found calves fed chopped hay separately from concentrate consumed hay at 40% of total daily feed intake. It is difficult to determine the cause of this variance between studies, however many variables could contribute to this difference such as quality and chop length of the forage, or type and quality of starter feed offered (Montoro et al., 2013).

Another consideration to be made when formulating calf diets is forage particle size. It has been shown that calves provided with a low level of alfalfa (8%) had increased DMI and weaning weight over calves fed same level of alfalfa at a shorter chop length (Mirzaei et al., 2015). In another study, calves fed coarse chopped grass hay mixed with calf starter had greater overall DMI and apparent digestibility when compared to calves fed the same diet composition with finely ground hay rather than chopped hay (Montoro et al., 2013). The increase in DMI, growth, and apparent digestibility of feed when calves are offered forage in addition to concentrate may be explained by an improvement in rumen environment (Montoro et al., 2013). Although there is a vast amount of literature available on solid feeding options for weaning age calves, there does not seem to be a general consensus on the best diet to promote rumen development, while encouraging early DMI level.

1.4 Social Housing at Weaning Time

Social housing of calves has been shown to stimulate growth and improve calf welfare (Chua et al., 2002). Calves housed in groups are more active (Chua et al., 2002) and show greater levels of play behaviour (Jensen et al., 1998), a behaviour associated with calf well-being (Spinka et al., 2001). Although there are a number of benefits of group housing, many commercial dairy farms still house calves individually due to previous evidence that this housing system promotes lower incidences of disease (Tomkins, 1991). However, more recent work has demonstrated that, when calves were offered either high or restrictive levels of milk, housing calves in pairs showed no effect on calf health (Chua et al., 2002; Jensen and Larsen, 2014). Therefore, it has been suggested that sanitation, ventilation and nutrition play a larger role in incidence of disease than physical contact with other calves (Chua et al., 2002). A possible negative effect of group housing seems to appear when calves are housed in large groups (12-24 calves) where competition for the milk source is present; calves in this type of housing situation tend to increase their rate of milk intake to compensate for decreased access to feed (Jensen, 2004). Calves kept in pairs during the weaning period show better weight gain due to higher DMI during milk weaning (Warnick et al., 1977; Chua et al., 2002; De Paula Vieira et al., 2010; Jensen et al., 2015). Calves housed in groups have also been shown to begin consuming concentrate and hay earlier than calves housed individually (Warnick et al., 1976; De Paula Vieira et al., 2010). Earlier consumption of solid feed and higher DMI for calves housed in groups is likely related to social facilitation of feeding behaviour (De Paula Vieira et al., 2010). Calves offered low levels of milk showed no effect of a social companion on feed intake, whereas calves fed high milk levels showed social facilitation of feeding when paired (Jensen et al., 2015). Researchers attributed this difference to hunger in restrictively fed calves; therefore calves were highly motivated to consume solid feed with or without a partner, eliminating the effect of social facilitation (Jensen et al., 2015). When housed individually and exposed to field tests at 3 months of age, calves were more fearful of novel calves and novel areas than calves housed in pairs (Jensen et al., 1997). When calves are housed in complex social groups, a reduction in food neophobia occurs (Costa et al., 2014), in addition to higher behavioural flexibility and increased ease of adaptation to new stimuli (De Paula Vieira et al., 2012). These traits could contribute to the lesser negative effect seen in paired or group housed calves during the weaning period. Calves that lack the social experience of calves housed in groups show greater vocalizations at weaning time, indicative of either hunger or response to weaning distress (De Paula Vieira et al., 2008;., 2010). Play behaviour has been shown to be greater in calves fed high milk levels and housed in pairs (Jensen et al., 2015). Interestingly, calves fed low levels of milk do not show a change in play behaviour when housed individually or in pairs (Jensen et al., 2015). This finding implies that there is a welfare benefit of pair housing calves such that calves that are better satiated participate in more play behaviour, a sign of good welfare (Jensen et al., 2015). Pair-housed calves show behavioural adaptation to weaning by increasing feeding time and meal frequency compared to calves housed individually shortly after weaning (De Paula Vieira et al., 2010). Calves housed in groups show greater behavioural flexibility and thus fewer signs of distress at weaning than calves housed individually.

If calves have been housed individually and are then introduced to a new group, this increases competitive interactions and in turn increases stress and decreases feed intake after mixing (Bøe and Færevik, 2003). Competition for resources in group pens can cause lower milk intakes when calves are forced to compete for access to milk, especially in situations with lower teat-to-calf ratios (von Keyserlingk et al., 2004). Milk consumption declines approximately 20%

on day of introduction to a group of 4 calves (O'Driscoll et al., 2006), while number of meals consumed on the day of mixing decreased over 50%. On the day of mixing, calves consume much larger meals at much greater feeding rates in an attempt to compensate for decreased meal frequency (O'Driscoll et al., 2006). Further research should be conducted on mixing in milk-feeding groups of larger, more practical group sizes for automated calf feeder systems. Calves previously kept in social housing situations hold higher social rank in groups after mixing than calves previously housed individually (Warnick et al., 1976; Duve et al., 2012). Thus, when mixing occurs post-weaning, it is a great source of distress for calves housed individually during the milk-feeding stage. Similarly, dynamic groups where a calf is added to a pre-existing group of older animals at a very young age are a source of stress for the younger members of the group (Mench et al., 1990). In this case, calves may alter their feeding behaviour to avoid competition with other calves, spending more time feeding at night (Babu et al., 2004). This reaction will skew normal feeding behaviour and may have an effect on overall calf health and well-being.

1.5 Behaviour and Time Budgets of Calves

Calves in modern dairy systems are not raised in a manner reflective of how they are raised by their dam in nature. To evaluate the management systems used for calf raising in today's dairy industry, researchers with interest in calf welfare have relied largely on behavioural measures focused on feeding behaviour, social interactions, and daily time budgets of calves at a young age. Behavioural measures are valuable resources that may be used to determine the biological appropriateness and effectiveness of calf raising programs. The use of these measures can aid in the improvement of calf rearing systems to promote the best growth and performance in young dairy calves, while encouraging natural behaviour, thus helping improve welfare of calves.

In modern systems, feeding behaviour in dairy cattle is largely influenced by management factors such as feed delivery (DeVries et al., 2005). Milk meal patterns are largely influenced by milk allowance and delivery method (Senn et al., 2000; Appleby et al., 2001; Miller-Cushon et al., 2013a). If calves are offered milk at a restrictive level, they have limited control of their daily milk intake patterns; however, when fed ad libitum, calves develop natural circadian patterns of intake (Senn et al., 2000). Teat-feeding ad libitum quantities of milk promotes feeding behaviour similar to that of calves left to suckle from the dam, smaller meals taking place more frequently throughout the day with peaks in feeding behaviour at sunrise and sunset (Senn et al., 2000; Appleby et al., 2001). O'Driscoll et al. (2006) reported calves spend approximately 1 h/d suckling the teat when fed ad libitum quantities of milk from an automated calf feeder, which is comparable to the time spent suckling when calves are left with the dam, according to a study by Day et al. (1987). When buckets are used for milk feeding, the high rate of milk intake can be disadvantageous for digestive processes due to the potential for incomplete closure of the oesophageal groove (Wise and Anderson, 1939) and the lack of digestive hormones triggered by sucking behaviour (de Passillé et al., 1992). Even when offered milk ad libitum, calves fed by bucket consume less milk, in less time than calves allowed to suck for their milk meals (Hammell et al., 1988). When provided restricted amounts of milk calves spend less time feeding and more time performing non-nutritive sucking (De Paula Vieira et al., 2008; Miller-Cushon et al., 2013a). Calves fed ad libitum quantities of milk via bucket, also spend more time performing non-nutritive sucking on a dummy teat (Hammell et al., 1988), demonstrating the strong motivation for sucking behaviour even in calves that are likely satiated by milk allowances. It has been suggested that offering forage is one potential solution to the problem of non-nutritive sucking (Castells et al., 2012).

As is the case with milk feeding, solid feeding patterns vary greatly with feed delivery and other management factors, including characteristics of the feed offered. With both milk and solid feed, calves show increased feeding time at feed delivery (Appleby et al., 2001; Miller-Cushon et al., 2013b). Feeding patterns may also be influenced by the type of feed presentation and type of solid feed. For example, calves fed a mix of chopped grass hay and grain (in a ratio of 30:70) showed greater feeding times and slower feeding rates than calves offered the same ingredients separately, while also demonstrating a more even diurnal distribution of feeding patterns throughout the day (Miller-Cushon et al., 2013b). Additionally, when offered feed as a mix, rather than components fed separately, older heifers also consumed feed in a more evenly distributed diurnal pattern (Greter et al., 2010). A more balanced intake of feed throughout the day contributes to a healthier rumen environment, thus feeding patterns present in animals fed mix diets may be beneficial to rumen health (Bach et al., 2007). Another aspect of feed presentation to consider when formulating calf diets is feed sorting. Sorting may negatively impact rumen health if calves sort for concentrate, thus consume an unbalanced ration (Miller-Cushon and DeVries, 2015). Leonardi and Armentano (2003) suggested that altering particle size and forage content of solid feed rations may decrease the occurrence of sorting behaviour in cows. Additionally, decreasing the dry matter content of feed in dairy cows has been shown to decrease feed sorting (Leonardi et al., 2005). It is beneficial to prevent dietary selection in calves, as there is potential for this behaviour to continue into adulthood (Miller-Cushon and DeVries, 2015).

Little research has been conducted on rumination time of dairy calves, possibly due to the large amount of labour required to accurately assess this behaviour. Rumination behaviour in dairy cattle is mainly regulated by the composition and digestibility of the feed offered and the neutral detergent fibre (NDF) content and quality of forage offered (Welch and Smith, 1970). Rumination time in cows has been shown to decrease with increased stress (Herskin et al., 2004). The recording of rumination behaviour in adult cows has become more automated with the use of rumination collars, validated for use by Schirmann et al. (2009). However, this type of system could not be validated for use in calves (Burfeind et al., 2011). Using live observation techniques, it was reported that the majority of calves begin ruminating in the first month of life and rumination time increases with increasing solid feed consumption (Swanson and Harris, 1958). When calves are offered coarse diets without roughage, rumination time is greater than when offered diets with fine particle size (Porter et al., 2007). The presence of forage in the ration promotes rumination in young calves (Phillips, 2004; Castells et al., 2012).

Another behaviour that is measured by very few researchers is the lying behaviour of dairy calves, to determine total daily lying time. Lying time in young calves may be influenced by social factors (Chua et al., 2002; von Keyserlingk et al., 2008) and environmental factors (Camiloti et al., 2012). Adult dairy cattle are highly motivated to rest for approximately 12 hours/day (Jensen et al., 2004). Previous research has shown calves spend approximately 70 to 80 percent of the day lying down (Panivivat et al., 2004) and that reduction in time spent lying down may have negative consequences on growth rate (Hänninen et al., 2005). Social factors, such as paired housing, as studied by Chua et al. (2002), do not seem to have an effect on lying behaviour, as there was no difference in lying time between individually-housed and pair-housed calves. Time spent standing increased with age in pre-weaned calves and did not change with season (Hill et al., 2013). Bedding quality has an impact on lying time in young calves; when provided bedding with higher moisture level, calves spend less time lying (Camiloti et al., 2012). If provided with a choice of bedding or concrete floors, calves never chose to lie on concrete floors (Camiloti et al., 2012). There is still a need for research investigating the standing and lying behaviour of calves fed high or restrictive levels of milk. Little is known about how the weaning period may affect lying behaviour; however it has been reported that lying time is greater for calves being weaned by volume reduction over calves weaned by dilution (Nielsen et al., 2008). Although weaning method shows potential as a factor effecting lying time, the frequency of lying bouts has been shown to be unaffected by milk intake level and method of delivery (Hammell et al., 1988). Further research is required now that there is a new, more convenient, and less labour intensive method of automatically recording this behaviour, validated for use in calves (Bonk et al., 2013).

Overall, behaviour of calves over the weaning period is not extensively documented. Research focused on behaviour during the weaning period of calves fed high levels of milk is necessary to fully understand the benefits and detriments of this feeding program on calf well-being.

1.6 Thesis Objectives

This review provides a summary of current knowledge of factors affecting the feed intake, growth and behaviour during the milk-feeding and weaning stages of calves fed high levels of milk. Previous research shows a strong understanding of the benefits of feeding calves high levels of milk and the importance of solid feed intake prior to weaning to maintain the growth benefits attained from enhanced pre-weaning nutrition. There is a need for increased knowledge of the behaviour and time budgets of calves in high milking feeding systems to better understand how to improve solid feed intake and reduce disruptions to natural behaviour at weaning. Further, it is necessary to investigate all possible diets and feed presentations, including forages available to young calves, to maximize pre-weaning solid feed intake and ease the transition from liquid to solid feed, while taking into account the role of social housing on feeding behaviour during the weaning period.

Therefore, the main objective of this work was to evaluate the daily time budget of calves on an accelerated milk feeding program in the weeks surrounding the weaning period, with and without the influence of a pen-mate. In addition, this thesis planned to assess changes in lying, rumination, and feeding behaviour and how these factors may affect calf-well-being at this stressful time, while assessing the effect of feed type and presentation offered to calves over this time period. The general hypothesis of this research was that housing calves in pairs would reduce the significant alteration of daily time budgets occurring around weaning to account for the change from milk to solid feed and that the provision of a higher forage diet would increase feed intake at weaning time. This hypothesis was addressed in two different studies with specific objectives:

1) To investigate the impact of weaning on the time budgets of dairy calves fed milk *ad libitum* and to determine the impact of social housing on negative behavioural changes that may occur at weaning.
2) To investigate a feeding strategy that could be utilized to ease the transition to solid feed using different types of diets containing forage.

CHAPTER 2: IMPACT OF SOCIAL HOUSING ON TIME BUDGETS OF DAIRY CALVES AROUND WEANING

2.1 Introduction

Increasing milk allowance improves the well-being of young dairy calves by decreasing symptoms of hunger (De Paula Vieira et al., 2008), encouraging natural suckling behaviour (Appleby et al., 2001), and increasing growth rates (Jasper and Weary, 2002). This feeding practice may also improve long-term performance when the calf enters the milking herd (Soberon et al., 2012). However, providing greater quantities of milk creates a challenge at weaning, since calves consume less solid feed prior to weaning when provided more milk (Miller-Cushon et al., 2013b; Terré et al., 2007) and may have poor weight gain during the weaning transition (Sweeney et at., 2010). Improvements to current weaning programs may help eliminate these set-backs. For example, increasing the duration of the weaning period (Sweeney et al., 2010), utilizing different methods of weaning (i.e. dilution, volume reduction; Khan et al., 2007), offering different types of solid feeds (Castells et al., 2012), or providing access to herd-mates (Chua et al., 2002) may improve the transition to solid feed over the weaning period.

Recent research has shown an improved feed intake during the weaning period in calves housed in groups rather than individually; this suggests that social facilitation of feeding exists and may be beneficial to calf growth and health over the weaning stage (De Paula Vieira et al., 2010). Effects of early social housing and early exposure to competition may have longer-term effects on calves, as there is evidence that calves previously housed in groups have greater competitive success immediately after weaning (Duve et al., 2012) and calves exposed to early competition exhibit increased competitive behaviour for access to feed 6 weeks after weaning (Miller-Cushon et al., 2014). Benefits of social housing and the potential to compete for feed at a young age may persist as the calf ages and allow these calves to perform better in competitive interactions post-weaning (Duve et al., 2012; Miller-Cushon et al., 2014).

There is little research, to date, characterizing behavioural changes over the weaning period. When milk reduction begins from high feeding levels, calves have been shown to increase their solid feed intakes (Sweeney et al., 2010). Calves housed in pairs consume more solid feed over this transition period than calves housed individually (De Paula Vieira et al., 2010; Jensen et al., 2015). Therefore, the objective of this study was to investigate the impact of weaning on the time budgets of dairy calves fed milk *ad libitum* and also to determine the impact of social housing on negative behavioural changes that may occur at weaning.

As calves increase their ingestion of solid feed, one would expect them to start ruminating more as rumen functionality develops, and be able to absorb the by-products of rumen digestion. Although there is little research to date observing rumination and BHBA levels at this stage of life, we expect to find higher daily rumination times and higher blood BHBA concentrations with calf age over the weaning period due to higher feed intakes and absorption of short-chain fatty acids from the rumen (Swanson and Harris, 1958; Quigley et al., 1992). During times of stress (i.e. social mixing) cows have been shown to decrease lying time temporarily (von Keyserlink et al., 2008), thus it is expected that calves may alter their normal lying behaviour during a high stress period such as weaning.

2.2 Materials and Methods

This study was part of a larger study aimed at evaluating how social housing affects development of feeding behaviour and social feeding habits of dairy calves. As such, detailed descriptions of the methodology of the study are presented in Miller-Cushon and DeVries (submitted). To address the current objectives, this study focused on the period around weaning (7 d prior, 10 d weaning period, and 7 d following), investigating daily changes in behaviour across this time period.

2.2.1 Animals and Housing

Twenty male Holstein calves were used in this study. Calves were purchased from local dairy farms (Eastern Ontario, Canada) and transported to the University of Guelph Kemptville Campus Dairy Education and Research Centre (Kemptville, ON, Canada). Prior to transport, it was confirmed that calves received a minimum of one feeding of colostrum and were tagged with a National Livestock Identification for Dairy tag before removal from the farm. Calves were assessed by study technicians at the farm of origin and only calves deemed healthy and alert were purchased. At the research farm, calves were managed under the standard operating procedures of the research centre, in accordance with the guidelines set by the Canadian Council on Animal Care (CCAC, 2009) and as approved by the University of Guelph Animal Care Committee. The day of arrival at the research farm marked d 0 of the study. Each new day of the trial began at milk feeding (0900 h). All calves received a 2 mL injection of a vitamin supplement containing vitamin E and selenium (Dystosel; Pfizer Animal Health, Kirkland, Canada) and a 1 mL injection of tulathromycin (Draxxin; Pfizer Animal Health) to prevent illness (Stanton et al., 2013). Calves were also given 2 mL of Inforce 3 (Pfizer Animal Health) intranasally on d 3 to prevent bovine respiratory syncytial virus, infectious bovine rhinotracheitis, and parainfluenza virus 3 related respiratory disease (Ellis et al., 2013).

Calves were randomly assigned to a treatment group upon arrival at the research farm: 10 calves were housed in pairs (**PH**), while the other 10 calves were housed individually (**IH**) until the first day after milk weaning (d 50) when they were switched to pair housing. Calves in each pair arrived at the farm on the same day and were paired immediately upon arrival. The research facility consisted of a covered structure with 3 closed sides. The south facing wall was open to provide air circulation while protecting calves from the elements. Calf pens were located along the rear wall of the building. Pens that housed pairs (n = 5, 10 calves) of calves (2.4 x 1.8m; width x depth) were alternated with 2 pens that contained calves (n = 10, 10 calves) housed individually (1.2 x 1.8m). All pens had 3 solid sides (1.3 m high) and a metal gate at the front fitted with 2 openings on each gate that allowed calves access to feed buckets mounted below. Pre-weaning, calves had access to two, 8 L capacity pails, one containing solid feed and one containing fresh water. Post-weaning, these buckets were exchanged for larger pails (20 L) containing the post-weaning solid feed and fresh water. Pens were bedded with wood shavings that were replenished as needed and fully replaced at least twice per week.

2.2.2 Milk Feeding Procedure

All calves had *ad libitum* access to milk replacer, mixed as directed at 150 g/L (Optivia Advantage Milk Replacer, Nutreco Canada Inc., Guelph, Canada; 26% CP, 16% fat). Milk replacer was mixed fresh every morning and the desired pH of the milk replacer (4.0 to 4.5) was achieved by adding a prediluted 9.8% formic acid solution (The Acidified Milk Solution, NOD Apiary Products Ltd., Frankford, Canada) to prevent microbial growth. An artificial teat (Peach Teats, Skellerup Industries Ltd. Woolston, New Zealand) was mounted to gate of each pen with a milk tube fitted with a one-way valve running into a covered bucket placed outside of the pen. In the case of the paired calves, 2 teats were mounted side by side and each hose led into the same bucket on the outside of the pen. Since calves were fed ad libitum, milk-feeding apparatus were removed at 0800h to be cleaned and orts weighed back before fresh milk replacer was offered at 0900 h each morning. Milk replacer was replenished and stirred as needed at 1600 h to ensure continued access. Milk weaning by dilution began at d 40 and ended on d 49. When implementing milk weaning by volume reduction, one calf in pair housing may consume a larger volume of milk leaving the other calf less milk. Since half of the calves were pair housed at this time, milk replacer was diluted on d 40, d 43, d 46 and d 49 by 25, 50, 75 and 100% respectively to prevent large variation in intake between pair housed calves. On d 49, calves were completely weaned and offered only water on this day through the milk feeding apparatus. On d 50 the system was fully removed from the pens.

2.2.3 Experimental Design and Diets

From the second week of life to the beginning of weaning, calves were offered ad libitum access to a textured dairy starter concentrate (Rooney's Feeds, Iroquois, ON: containing: 36.5% corn, 28% calf starter supplement (Shur-Gain, Nutreco Canada Inc., Guelph, ON, Canada), 20% rolled barley, 2.5% dilute monensin sodium, 2% molasses, 1% soybean oil). The post-weaning feed (Shur-Gain High Fiber Dairy Heifer Ration, 20% protein; Shur-Gain Nutreco Canada Inc.) was mixed at a rate of 50:50 with the pre-weaning starter feed during the weaning period to ease the transition to the new diet. Fresh feed was offered at 1000 h daily, at this time orts were weighed and discarded.

Daily intakes of concentrate, milk replacer and water were recorded at the pen level. Intakes were calculated based on weight offered and the quantity refused at the start of the following day. Orts were removed and either sampled or discarded. To ensure at libitum access to solid feed, an orts level of >15% was maintained. Fresh and orts samples were taken weekly (1 fresh, 1 orts/pen) to determine accurate DMI. All samples were frozen at -20°C until time of analysis. Samples were then thawed and dried in an oven at 55°C for 48 h to determine DM content of the feed.

2.2.4 Calf Behaviour and Physiological Measures

Calves were fitted with data loggers (HOBO Pendant G Data Logger, Onset, Pocasset, MA) to assess standing and lying behaviour over the weaning period (as validated for use in calves by Bonk et al., 2013). Loggers were secured onto the rear leg with bandage tape (Vetrap Bandaging Tape, 3M, London, ON, Canada) as per UBC AWP (2013). On d 33, calves were fitted with loggers. These loggers were removed and replaced on d 41, and again on d 49, to ensure continuous data collection. At each change the new loggers were secured to the opposite rear leg. The devices were removed on d 57. Data was collected for standing and lying times, as well as length and frequency of all lying bouts.

Rumination was recorded by live observation on alternating days beginning on d 34 and ending on d 56. On these days, 1 min scans were performed for 1 h beginning at 1200 h and ending at 1300 h for a total of 60 observations/calf/d. This observation period was selected based on the delay from feeding used by Montoro et al. (2013), where researchers observed rumination behaviour 1 h after solid feed delivery. Six colour video cameras (day/night camera, model no. WV-CP504; Panasonic, Osaka, Japan) with F0.95/2.8 to 8 mm lenses (Fujinon CCTV lens; Fuji, Tokyo, Japan) recorded continuously at 15 images/s for the duration of the study. A digital video recorder (digital disk recorder, model no. WJ-HD616K; Panasonic) received video feed from these cameras and allowed viewing of the video footage for analysis. Cameras were mounted 4 m from the barn floor and 2 m from the front edge of calf pens. The front of each pen was clearly visible on at least one camera to allow a clear view of feed buckets and milk feeding apparatuses. To obtain clear night time recordings 5 red lights (100 W) were spaced evenly between cameras and set to turn on at nightfall. Feeding behaviour was observed on days corresponding to live observation of rumination; for all 12 d of behavioural recording, video data were analyzed using instantaneous scans at 1-min intervals for milk-feeding and solid feed consumption (as validated by Miller-Cushon and DeVries, 2011b). Milk-feeding was noted if a calf had its mouth closed on the teat and with milk flow through the hose. Solid feed consumption was recorded if the calf's head was lowered into the feed pail. Water intake was noted if the calf had its head lowered into the water pail. To calculate feeding rate, total daily feeding time was divided by total solid feed (on a dry matter basis), in grams, consumed that day.

To determine blood BHBA concentration, as a proxy for rumen physiological development (Brown et al., 2014), throughout the trial, a Precision Xtra meter (Abbott Diabetes Care, Saint Laurent, Canada; validated in cows by Iwersen et al., 2009) was used with blood ketone test strips (Abbott Diabetes Care). This test was performed on days corresponding to the live observation of rumination and video observation of feeding behaviour at 1300h for a total of 12 collection d. Tests were performed by drawing a very small amount of blood (less than 1mL) from the coccygeal vein. A droplet of blood was then placed on the test strip and the reader indicated results of blood BHBA concentration in mmol/L.

2.2.5 Statistical Analysis

One calf in the pair housed system did not thrive during the pre-weaning and weaning period and was later euthanized. Data from this calf and partner was removed from analysis.

For both IH and PH calves, data was summarized at a pair level and then expressed on a per calf basis. All data collected was summarized and analyzed by stage: pre-weaning (d 33 - 39), weaning (d 40 - 49), and post-weaning (d 50 - 56) and by d within stage. Before any analysis was performed all data was screened for normality using the UNIVARIATE procedure of SAS (SAS Institute Inc., 2008).

Data were analyzed using the MIXED procedure of SAS, treating day as a repeated measure. The model included the fixed effects of treatment, day and treatment × day interaction. Heterogeneous autoregressive was selected as the variance-covariance matrix structure on the basis of best fit according to Schwarz's Bayesian information criterion for DMI and milk intake data, while autoregresssive was selected for milk and solid feeding time, water intake and BHBA data. Compound symmetry was selected as the variance-covariance matrix structure for lying behaviour and rumination data. Multiple comparisons were analyzed for variables with a treatment x day interaction using the Tukey-Kramer adjustment.

An analysis of diurnal patterns of feeding was performed on milk feeding time for the pre-weaning and weaning phase, as well as on solid feeding time for all 3 phases. Time spent performing these behaviours were summed hourly and averaged by calf across all recording days in each phase. Data were analyzed using the MIXED procedure of SAS, treating hour as a repeated measure. The model included treatment, hour and treatment x hour interaction as fixed effects. Autoregressive was selected as the variance-covariance matrix structure on the basis of best fit according to Schwarz's Bayesian information criterion. All values reported are least square means. Significance was declared at $P \leq 0.05$, and tendencies were reported if $0.05 \leq P \leq 0.10$.

2.3 Results

During the 7 d prior to weaning, all calves consumed large volumes of milk replacer (12.0 ± 2.12 L/d), and low levels of solid feed (Figure 2.1; $P = 0.05$). Milk intake increased with calf age pre-weaning ($P < 0.001$), but showed no effect of treatment ($P = 0.45$). Milk feeding time was consistent for the week pre-weaning and similar between treatments (37.4 ± 6.37 min/d). Milk feeding rate was also similar between treatments during the pre-weaning phase

(52.6 ± 10.73 g DM/min). Calves housed in pairs consumed more solid feed during this time than IH calves (0.14 vs 0.05 kg/d; SE = 0.046; P = 0.01), but solid feed intake was low for both groups (Figure 2.1). There was no effect of calf age on time spent consuming solid feed in the pre-weaning stage (P = 0.17). Although there was no effect of treatment on rate of solid feed intake across the pre-weaning period (6.1 ± 2.16 g DM/min; P = 0.28), PH calves tended to spend more time feeding than IH calves (16.6 vs 10.4 min/d; SE = 3.74; P = 0.09) during this time (Figure 2.2).

During the weaning phase there was no treatment effect on milk feeding time; calves spent approximately 43.6 ± 6.44 min/d drinking milk, as the total volume offered did not change over the weaning period due to dilution of the milk ration. There was a tendency (P = 0.09) for an increase in milk feeding time with age over the weaning period. Feeding rate of milk showed a treatment difference on the first day of weaning; IH calves drank faster than PH calves on this day (45.8 vs 36.5 g/min; P = 0.03). Diurnal feeding patterns for milk intake during the weaning period are shown in Figure 2.3a. Milk feeding time varied throughout the day, with no effect of treatment, with peaks around 0900, 1300, and 1900 h. All calves increased their solid feed intake rapidly over the weaning period (P < 0.001; Figure 2.1). Calves housed individually consumed less solid feed over the weaning phase than their PH counterparts (0.25 vs 0.55 kg/d; SE = 0.216; P = 0.03). There was an increase in time spent consuming solid feed with calf age (P < 0.001) during the weaning phase (Figure 2.2) for both treatment groups. Feeding rate of solid feed increased over time for all calves (P < 0.001) and calves on the PH treatment had a greater feeding rate than IH calves during this period (13.4 vs 6.6 g DM/min; SE = 2.16; P = 0.01). Diurnal patterns of solid feed consumption were similar (P = 0.95) during the weaning period (Figure 2.3b) for both treatment groups, showing peaks in feeding time around 0900 and 2000 h.

Post-weaning, feed intake continued to increase (*P* < 0.001) with age for all calves, with no difference between treatment groups (Figure 2.1). After weaning, IH calves tended to spend more time feeding than PH (132.5 vs 103.5 min/d; SE = 17.49; *P* = 0.06). During this time, feeding rate increased rate with calf age (*P* < 0.001) but was similar between treatments (15.9 ± 2.87 g/min; *P* = 0.11). Post-weaning diurnal patterns of solid feeding time differed by treatment (*P* = 0.01; Figure 2.3c). Calves previously housed individually in single pens spent more time feeding in the early hours of the day than calves housed in pairs.

Water intake was similar between treatments pre-weaning (3.8 ± 1.07 L/d) and rose quickly, and similarly, for all calves during weaning (Figure 2.4). Water intake showed an interaction of treatment and day (*P* <0.001) during weaning. On d 49, water intake peaked for both groups; however, IH calves consumed more water than PH calves on this day (21.9 vs 16.0 L; SE = 1.45; *P* = 0.02), adjusting for multiple comparisons. Post-weaning water intake remained consistent over time and did not differ between treatment groups (*P* = 0.24).

Lying time was not affected by treatment or calf age during the pre-weaning stage (1073.6 ± 25.02 min/d; P = 0.68). During the weaning and post-weaning phase, lying time showed an interaction of treatment and day (*P* = 0.04; Figure 2.5). While lying time decreased with calf age during weaning for all calves, however during this time PH calves spent less time lying than IH calves. Post-weaning, on d 50, when IH calves were paired, they experienced a decrease in lying time, while calves paired from the start of the study showed an increase in lying time (*P* = 0.04). During the remainder of the post-weaning period, lying time became stable and there was no longer a notable treatment difference (Figure 2.5). Lying bouts showed no significant difference between calves on differing treatments during the entire trial, after a

Tukey-Kramer adjustment (Figure 2.6); however number of bouts decreased by day during the weaning period ($P < 0.001$) and tended to increase with calf age post-weaning ($P = 0.06$).

Rumination was similar between treatments for the duration of the 24 d observation period ($P = 0.38$). Rumination time did not change from the pre-weaning (8.3 min/h) to weaning phase (8.7 min/h; $P = 0.78$). From the weaning to post-weaning stage, rumination time decreased for all calves (8.7 vs 3.1 min/h; SE = 2.91; $P < 0.001$).

There were no treatment differences in blood BHBA concentrations for the entire duration of the trial. Blood BHBA concentration was negligible (0.0 ± 0.01 mmol/L) prior to weaning (Figure 2.6). During the weaning period, BHBA rose with calf age (0.2 ± 0.02 mmol/L; $P = 0.01$). The most notable change in BHBA occurred between d 48 and d 50, the first day post-weaning ($P < 0.001$) when BHBA increased substantially as shown in Figure 2.7. After that time point, BHBA remained constant for the remainder of the post-weaning observation period.

2.4 Discussion

There is little research to date that describes the daily time budgets of dairy calves during the weaning period. The goal of the present study was to determine the effects of weaning calves off a high level of milk on time budgets at weaning, as well as the impact of social housing at this time. Results suggest that both IH and PH calves experienced behavioural changes around weaning time that may be indicative of a decrease in well-being.

Since all calves were fed milk replacer *ad libitum*, there was a very low level of solid feed intake prior to weaning, consistent with previous research (Jasper and Weary, 2002). Although all calves consumed low levels of solid feed during the milk-feeding stage, solid feed DMI rose with calf age. Calves housed in pairs consumed more solid feed prior to weaning and during the weaning period, likely due to social facilitation (De Paula Vieira et al., 2010). Costa et al. (2014) recently showed food neophobia was decreased in calves housed in complex social groups. Similar results from this group also indicated that calves housed in groups show more behavioural flexibility and a higher degree of ease to adapt to novel stimuli (De Paula Vieira, et al., 2012). This behavioural flexibility associated with social housing may decrease negative behavioural changes at weaning time.

Time spent consuming solid feed did not change with increasing calf age in the pre-weaning phase due to very low overall intake of calf starter across treatments until weaning began. The increase in solid feeding time and solid feeding rate with calf age during the weaning phase follows the increase in feed intake with the decreasing concentration of milk replacer available to the calves at that time. These results are consistent with other studies where calves have been weaned off ad libitum milk allowance (Chua et al., 2002; Jasper and Weary, 2002). Calves on the PH treatment tended to spend more time feeding at a faster rate during the weaning phase, likely due to the higher solid feed consumption and social facilitation of feed intake of PH calves.

Post-weaning, DMI continued to increase with calf age similarly for all calves. Post-weaning calves avoided altering their daily time budget by increasing their feeding rate to consume more DM, rather than increasing feeding time. During the post-weaning phase IH calves tended to spend more time feeding than PH calves. These calves also spent more time feeding in the early morning hours than the PH calves. This may reflect adjustment to the pair-housing system and the potential introduction of competition with a pen mate. O'Driscoll et al. (2006) demonstrated that, in a possible attempt to adapt to changes in social hierarchy, calves may alter feeding patterns to avoid competition for resources. Further, cows in competitive situations decrease feeding synchrony with other cows and avoid conflict with herd-mates by spending more time feeding at night (Olofsson, 1999). Thus, the previously IH calves in this study may have required further opportunity to develop synchronized feeding behaviour with their new partner, a behaviour that is common in pair-housed calves (Miller-Cushon et al., 2014). Additionally, it has been reported that calves with prior experience with competition for feed will have higher success rates in future competitive situations (Duve et al., 2012). Therefore, it is possible that although calves in the present study did not have to compete for resources (two teats and two feed pails were present in each paired pen), the IH calves may still have had to adjust to the potential of their pen-mate displacing them at the feed bucket, thus altering their diurnal feeding patterns.

In a study by Kertz et al. (1984), when water availability was low, calf starter intake decreased in weaned calves. Despite importance for DMI and health, water intake is often overlooked in calf nutrition studies (Kertz et al., 1984). In the current study, water intake remained low for the pre-weaning period while milk was offered ad libitum. Interestingly, water intake remained low early on in the weaning phase and showed an increase on the last day of the weaning period, more so for IH calves. This intake pattern is likely resultant of a combination of a number of factors. Calves were fed diluted milk during the weaning phase, thus, although DM content of the liquid diet decreased over this time period the overall intake of water remained relatively constant. Water intake, from the water pails, was low until d 49 when water was also offered through the milk apparatus, therefore, it appears calves experience a large increase in water intake on that day, although in the 3 days prior to this, when milk was diluted with 75% water, they consumed large amount of water in the diluted milk ration. Researchers have previously shown that weaning by volume reduction rather than dilution encourages more solid feed intake and greater daily lying time (Nielsen et al., 2008), so it is likely that calves weaned by dilution do not consume as much solid feed as they maintain a high consumption level of liquid feed. However, when housed in pairs it is difficult to successfully wean by volume reduction since more dominant calves may consume a greater portion of the reduced volume of milk than their companion. On d 49, the dilution rose from 75% water/25% milk replacer to purely water in the milk feeding apparatus. This procedure likely encouraged water intake since water was available via the milk feeding system from which calves were accustomed to drinking milk. The difference in IH and PH calves' water intake on d 49 can most likely be attributed to a level of frustration as a result of milk weaning. Evidence of increased behavioural flexibility (De Paula Vieira et al., 2012) leads to the suggestion that perhaps IH calves had a lower ability to cope with the change in feed than calves in the PH system. Additionally, one could speculate that since PH calves had the ability to redirect some of their frustrated sucking behaviour from the teat to their pen-mate, they may have consumed less water. We were unable to score the frequency of cross-sucking in this current study, and thus encourage further work to test this hypothesis.

To date, very little research has been conducted on lying behaviour of dairy calves around the time of weaning. In the current study, lying behaviour of all calves was consistent for the duration of the pre-weaning phase, similar to the results of a study by Chua et al. (2002) in which calves in individual pens and paired groups spent the same amount of time lying throughout their 8-wk study. Unlike the results of the aforementioned study, the current study found PH calves spent less time lying during the weaning phase. Chua et al. (2002) demonstrated that calves housed individually tended to spend more time lying, while calves in pairs spent more time standing idly and more time moving around the pen than IH calves. We speculate that PH calves in the current study spent less time lying due to higher activity level than that of the IH calves, which was exacerbated by the change in milk concentration offered during this time period. Calves housed in pairs spend more time engaged in play behaviour than calves housed individually (Jensen et al., 1997), thus is it possible that increase in play behaviour could result in decreased lying time. However, this change in behaviour occurred during the weaning period when milk reduction began, a factor shown to cause decreased play in PH calves (Jensen et al., 2015). It is likely that the current study would not have shown this difference in play behaviour, as calves were weaned gradually, by dilution, rather than the more abrupt method used in the previous study. Post-weaning, on d 50, IH calves experienced a large decrease in lying time that was not seen in the PH calves; this change correlates to the day of pairing for these calves. von Keyserlingk et al. (2008) reported decreased lying time on the day of mixing for adult cattle, but this change did not persist to the same extent past the day of mixing, similar to the results of the current study. Thus, it appears that the IH calves were sufficiently adjusted to their new pen-mates 1 d post-mixing as there was no longer a treatment difference in lying time from d 51 forward. Lying bouts were most frequent during the pre-weaning stage for both treatments when calves were younger and spent less time engaged in feeding behaviour. Frequency of bouts per day was similar to that reported in calves of comparable age (Bonk et al., 2013) to pre-weaning calves in the current study. Lying bouts decreased by day during the weaning and post-weaning period, which follows the decrease in lying time and increase in feeding time seen in these phases, demonstrating that calves alter their lying behaviour to accommodate changes in feeding behaviour.

Although PH calves had higher DMI levels than IH calves during the pre-weaning and weaning stages, this did not translate into increased rumination time. Contrary to our hypothesis, rumination behaviour did not change from the pre-weaning to weaning phase as calves began to consume more solid feed. Even less expected was the observed decrease in rumination time from the weaning phase to the post-weaning phase, when the largest increase in DMI occurred. These results are likely a consequence of the time of day selected for observation of this behaviour. Analysis of feeding patterns show that calves in this study, on both treatments, were still spending a large amount of time eating during the observation time for rumination, thus they were likely not ruminating at this time. There is very little research on rumination behaviour of calves at this age, thus, for future research if 24-h observation of rumination is not possible, more research is required to determine more effective observation periods within the day.

Previous studies of blood BHBA levels around weaning have also shown an increase in blood BHBA concentration with increased calf age and starter intake (Quigley et al., 1992; Coverdale et al., 2004). The increase in blood BHBA concentration over the weaning period is attributed to the increased production of butyrate from the fermentation of solid feed (Coverdale et al., 2004). This process increases the development of ruminal papillae, thus calves with higher blood BHBA levels are said to have higher rumen development (Khan et al., 2011). Since PH calves consumed more feed prior to the day of weaning, we expected to see some increase in blood BHBA concentration compared to IH calves, to indicate greater rumen development. It is likely that the high variability in BHBA between treatments makes it difficult to make any observations of treatment difference.

2.5 Conclusions

Calves altered their pre-weaning time budgets to accommodate the behaviour changes necessary to experience successful weaning. Solid feed intake and feeding rate increased over time during the 24 d of observation, while lying time and lying bout frequency decreased. Blood BHBA levels increased with increasing solid feed intake over the weaning period; thus this calf-side measure shows promise as a valuable and practical approach to measuring rumen development. During the weaning period the presence of a social partner reduced the negative effect of weaning on DMI and increased feeding rate. Further, results suggest that pair housing calves from birth may prevent disruptions to normal behaviour that occurs when calves are paired at weaning time.

2.6 Acknowledgments

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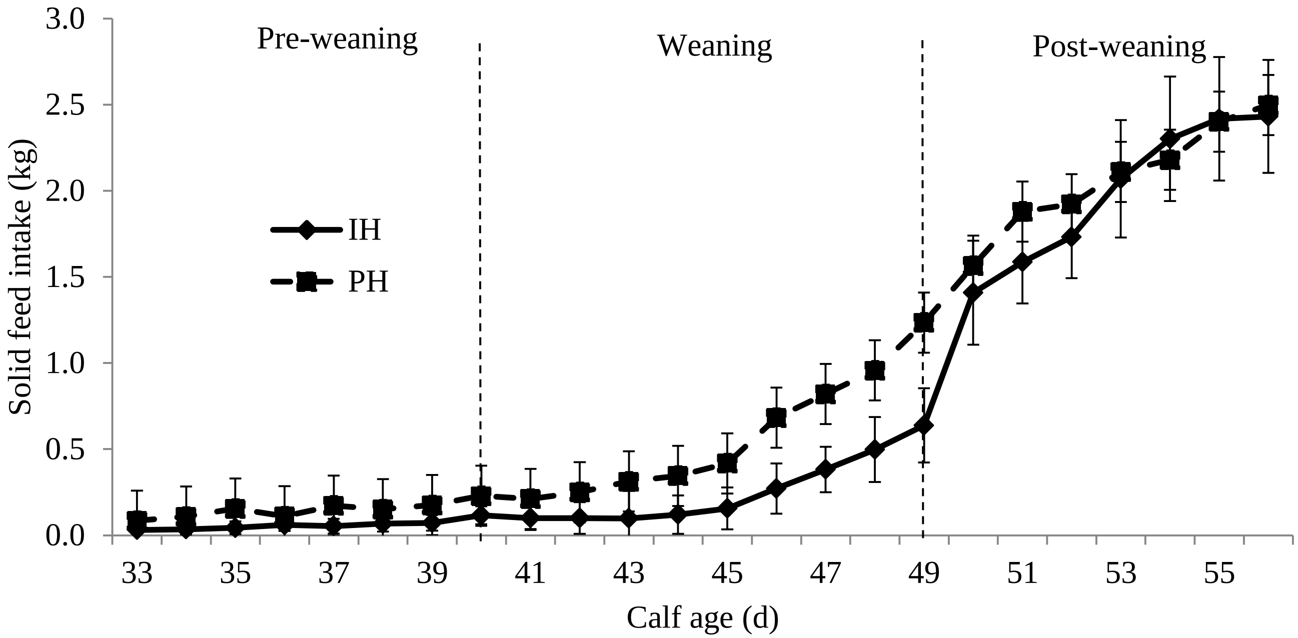

Figure 2.1: Mean (± SE) daily solid feed intake (DM). Values are shown separately for calves housed in individual pens for the pre-weaning and weaning stage, then pair-housed post-weaning (IH) and calves housed in pairs for the entire trial (PH).

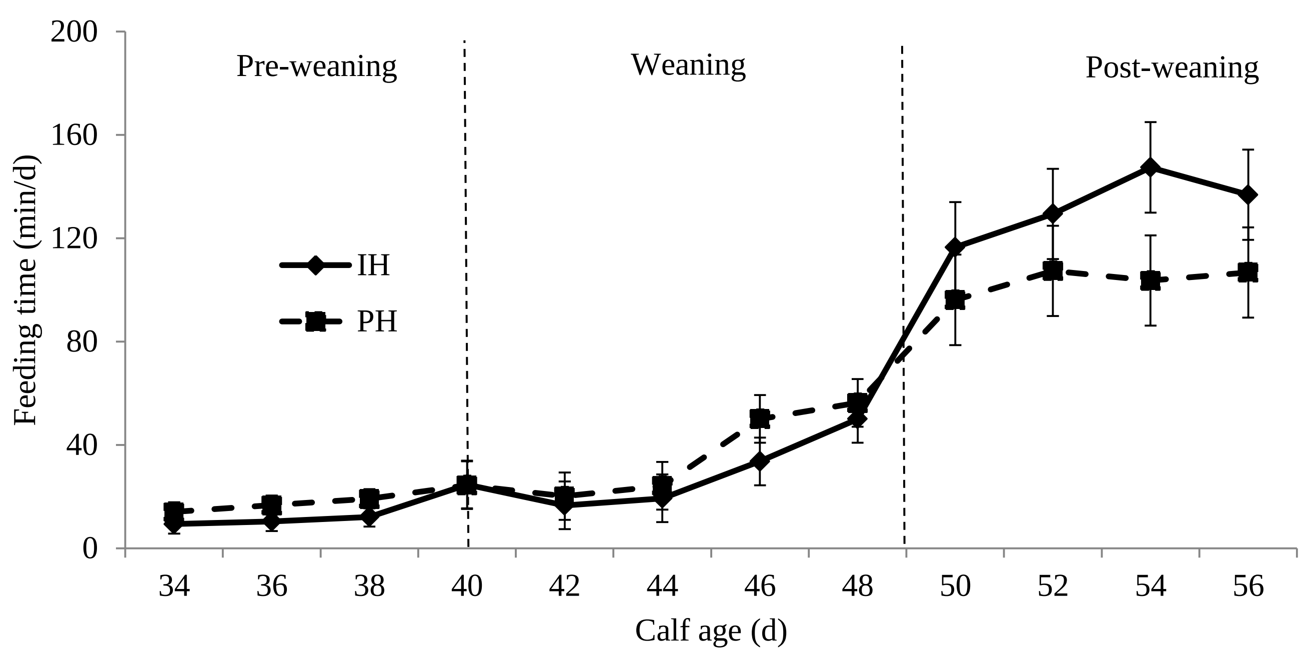

Figure 2.2: Mean (± SE) daily solid feeding time. Values are shown separately for calves housed in individual pens for the pre-weaning and weaning stage, then pair-housed post-weaning (IH) and calves housed in pairs for the entire trial (PH).

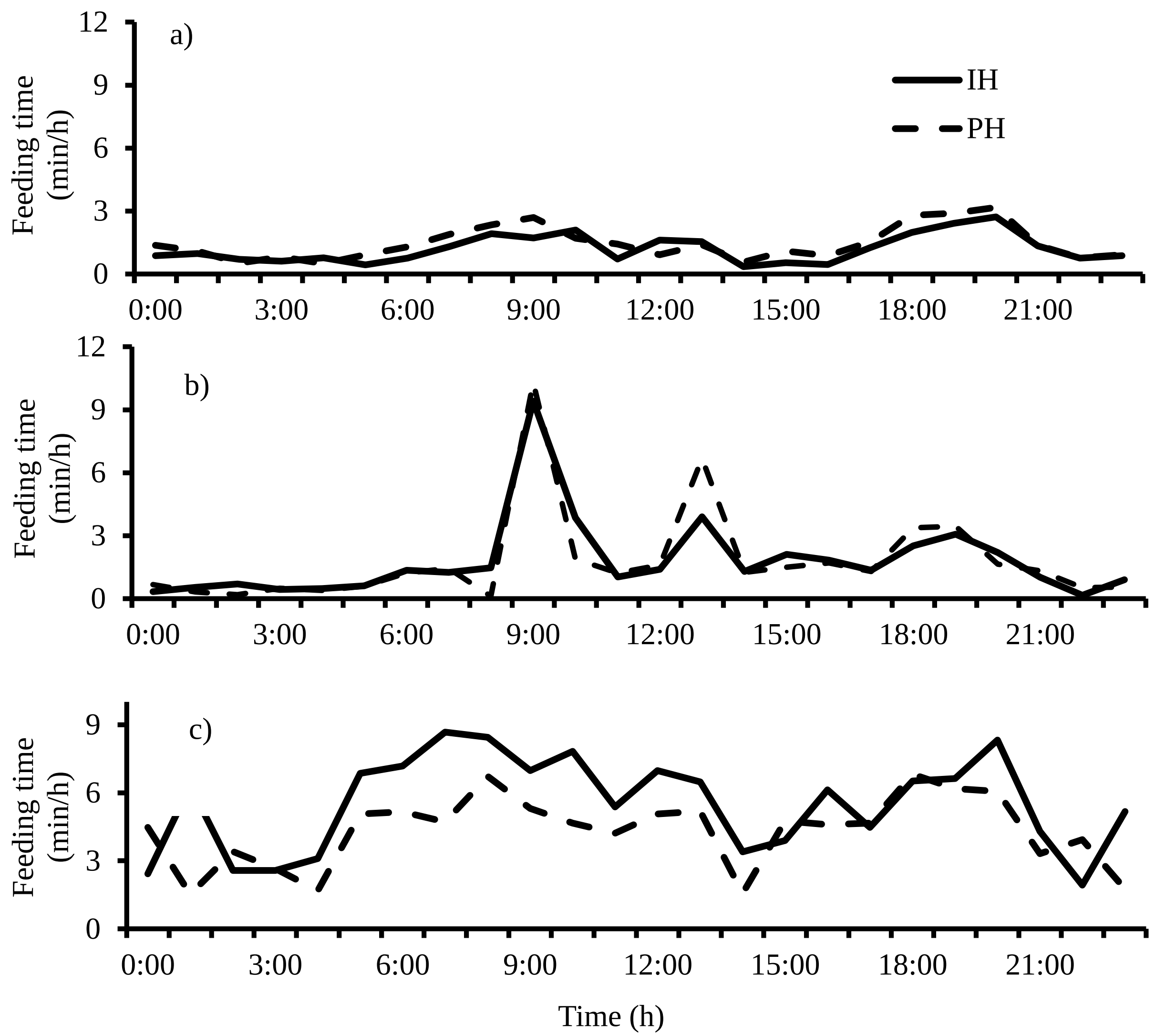

Figure 2.3: Diurnal feeding patterns of milk feeding (a) and solid feeding (b) for calves during the weaning period (d 40 – 49) and solid feeding (c) for calves during the post-weaning period (d 50 – 56). Values are shown separately for calves housed in individual pens for the pre-weaning and weaning stage, then pair-housed post-weaning (IH) and calves housed in pairs for the entire trial (PH).

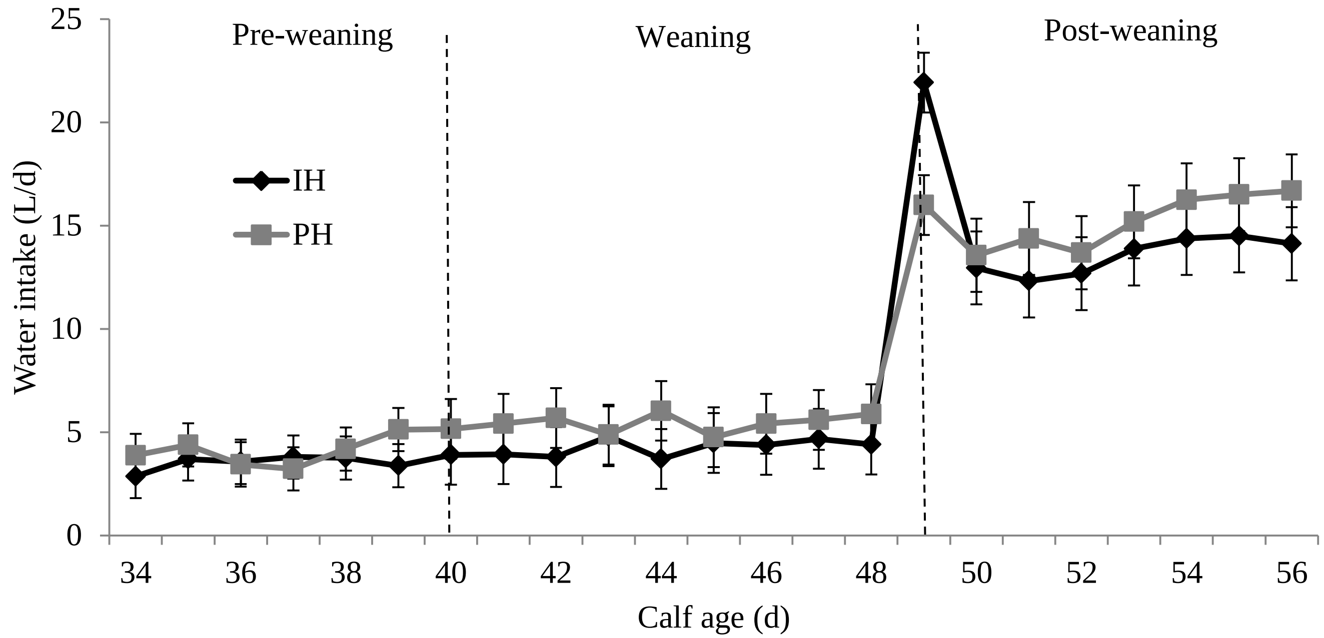

Figure 2.4: Mean daily water intake. Values are shown separately for calves housed in individual pens for the pre-weaning and weaning stage, then pair-housed post-weaning (IH) and calves housed in pairs for the entire trial (PH).

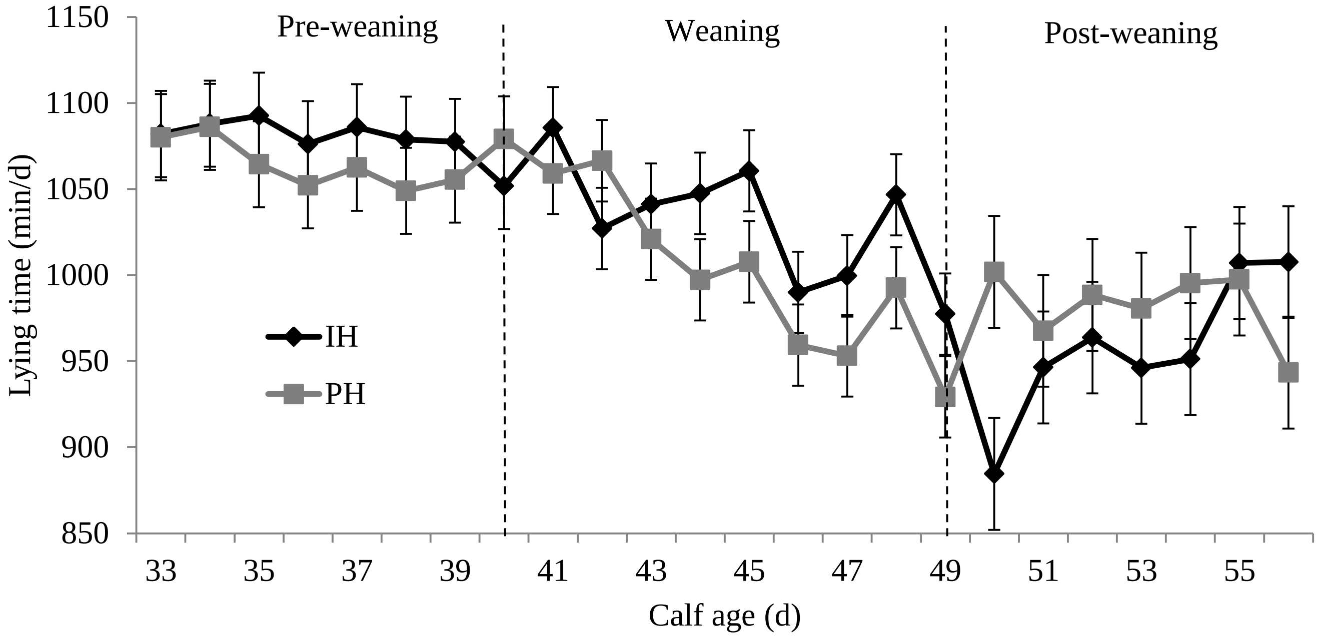

Figure 2.5: Mean daily lying time. Values are shown separately for calves housed in individual pens for the pre-weaning and weaning stage, then pair-housed post-weaning (IH) and calves housed in pairs for the entire trial (PH).

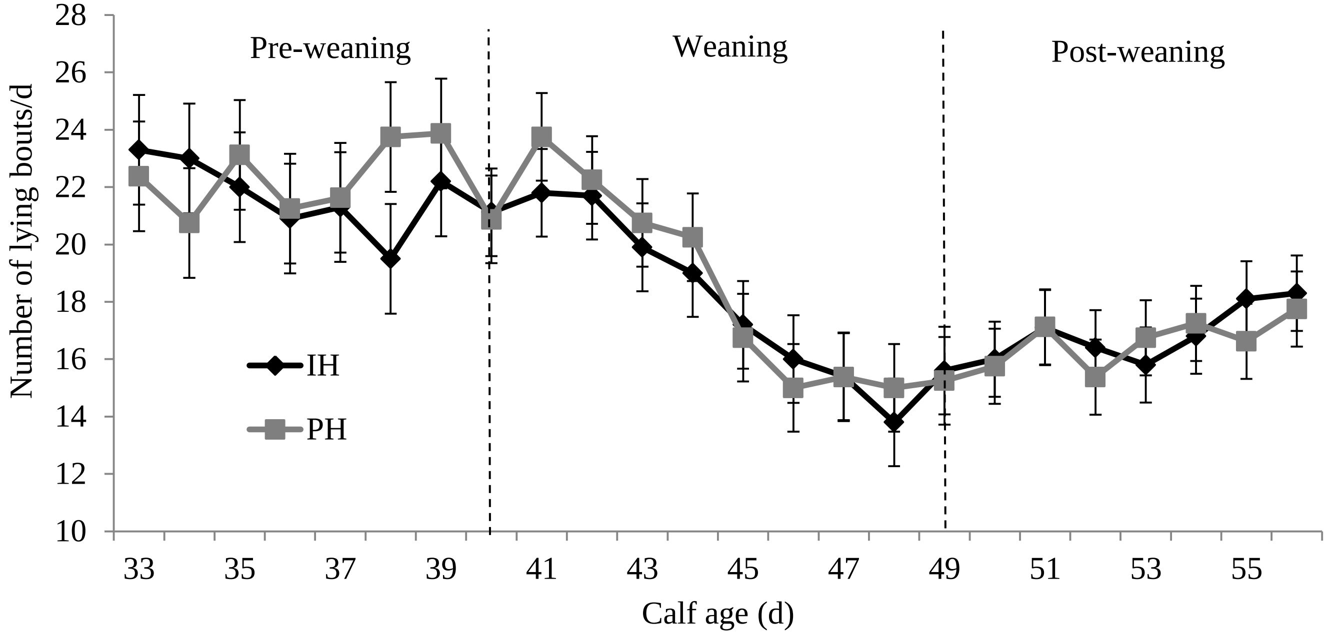

Figure 2.6: Mean daily lying bouts. Values are shown separately for calves housed in individual pens for the pre-weaning and weaning stage, then pair-housed post-weaning (IH) and calves housed in pairs for the entire trial (PH).

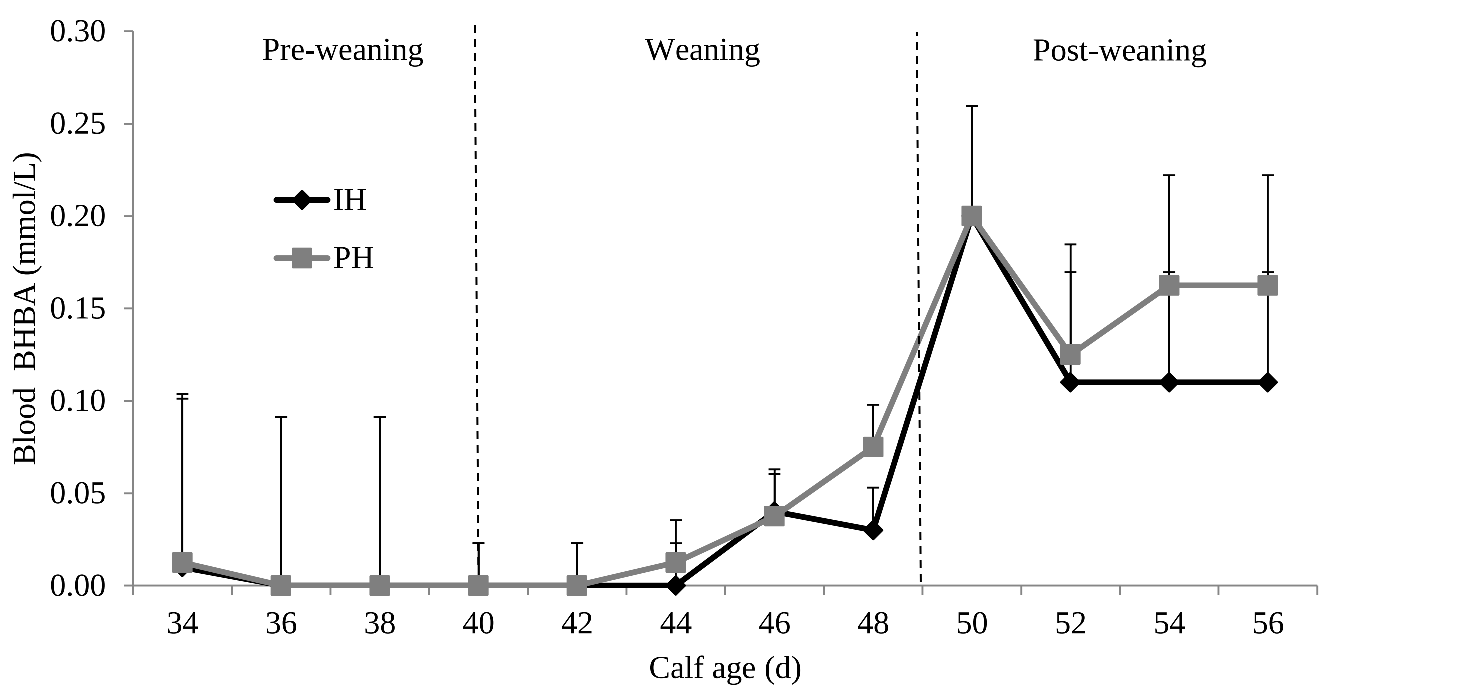

Figure 2.7: Mean blood BHBA concentration of calves. Values are shown separately for calves housed in individual pens for the pre-weaning and weaning stage, then pair-housed post-weaning (IH) and calves housed in pairs for the entire trial (PH).

CHAPTER 3: EFFECT OF FEED TYPE AND METHOD OF PRESENTATION ON FEEDING BEHAVIOUR, INTAKE, AND GROWTH OF DAIRY CALVES FED A HIGH LEVEL OF MILK

3.1 Introduction

Increasing the level of milk feeding for dairy calves in the early weeks of life can enhance growth rates (Appleby et al., 2001; Jasper and Weary, 2002) and may also result in development of healthier, higher-producing cows (Terré et al., 2009; Soberon et al., 2012). A potential challenge of enhanced milk feeding appears at weaning. Traditionally-fed calves, consuming low quantities of milk, are encouraged to ingest higher levels of concentrate prior to weaning (Khan et al., 2007a). Alternatively, calves fed higher levels of milk experience a challenge at weaning due to low consumption of solid feed prior to weaning (Jasper and Weary, 2002); thus there is some concern that their digestive systems are not accustomed to the digestion of such feed at weaning (Terré et al., 2007). Despite implementation of gradual weaning programs, a decrease in overall DMI is an issue for high milk-fed calves (de Passille et al., 2011).

The provision of forages, such as hay, may improve feed intake and rumen development (Castells et al., 2012). Previously, the inclusion of forage in the diets of milk fed calves was discouraged, despite the fact that this ingredient aids in muscular development of the rumen (Hamada et al., 1976), because it was also thought to inhibit the development of the rumen papillae (Tamate et al., 1962). In several studies, hay intake has been reported to displace the intake of higher quality starter (Stobo et al., 1966; Kertz et al., 1979; Hill et al., 2008). However, much of the research that contributed to that idea was conducted on calves fed low levels of milk that were insufficient for optimal growth. Recently, Khan et al. (2011) showed evidence that providing hay to calves fed with high milk allowances resulted in increased solid feed intakes and normal rumen development. These authors indicated that in a situation of restricted nutrient availability, hay intake could displace starter intake due to the resultant gut fill from consuming large amounts of hay. However, in a high milk feeding system, a gradual weaning program is typically recommended, ensuring a gradual transition from liquid to solid feed (Sweeney et al., 2010). Additionally, an improvement in digestibility was reported by Montoro et al. (2013) when concentrate was mixed with coarsely chopped grass hay rather than the finely chopped alternative. This novel finding suggests that not only forage type, but forage particle size, may also play a role in rumen development of young calves.

Recently, there has been interest in providing calves fed on higher milk levels with a silage-based total mixed ration (TMR). Not only would TMR be practical for the dairy farmer, as they could potentially use the same TMR given to the lactating cows, but it could also provide a balanced, palatable source of nutrients for the developing young ruminant. This type of high-fiber ration could potentially encourage rumen development and, therefore, create a smoother transition to solid feed. Thus, the objective of this research was to investigate a feeding strategy that could be utilized to ease the transition to solid feed using different types of higher forage diets. It was hypothesized that incorporating a silage-based TMR into the diets of calves fed high levels of milk prior to weaning would have no detrimental effects on the calves' growth and result in a positive effect on feeding behaviour. Similarly, it was hypothesized that calves fed diets including forage would exhibit more rumination behaviour. Calves provided with forage were hypothesized to consume more solid feed than calves fed only concentrate. As a result it was expected that calves fed forage and mixed diets would devote a greater portion of the daily time budget to feeding than calves fed no forage.

3.2 Materials and Methods

3.2.1 Animals and Housing

Forty-eight male Holstein calves were used in this study in 2 blocks of 24 calves. Each block was run over a 12-wk period. The first block ran from April to July and the second from July to October. Calves were purchased from local dairy farms in Eastern Ontario (Canada) before 1 d of age. National Livestock Identification for Dairy tags (Allflex Canada, St. Hyacinthe, Canada) were applied before removal from the farm of origin. It was confirmed that calves received at least one feeding of colostrum prior to pick up. At the time of purchase each calf was assessed by the study technicians and only calves deemed healthy and alert were included in the study. Calves were transported <25 km, in a well-bedded compartment, from their farm of origin to the University of Guelph Kemptville Campus Dairy Education and Research Centre (Kemptville, ON, Canada). The date of arrival at the research center was marked d 0 for each calf. Upon arrival calves were managed under standard operating procedures of the research centre, in accordance with the guidelines set by the Canadian Council on Animal Care (CCAC, 2009) and as approved by the University of Guelph Animal Care Committee. Calves each received a 2 mL injection (IM) of a supplement containing vitamin E and selenium (Dystosel; Pfizer Animal Health, Kirkland, Canada) and a 1 mL injection of tulathromycin (Draxxin; Pfizer Animal Health) on d 0 to protect from illness (Stanton et al., 2013). In addition they were given 2 mL of Inforce 3 (Pfizer Animal Health) intranasally for the prevention of respiratory disease caused by bovine respiratory syncytial virus, infectious bovine rhinotracheitis, and parainfluenza virus 3 (Ellis et al., 2013).

The calf barn at the research facility was a 3-sided building allowing for natural ventilation while protecting the pens from direct exposure to the elements. Calves were housed individually in pens (1.2 x 1.8 m; width x depth) with 3 solid sides (1.3 m high) and a metal gate at the front that allowed calves to reach through for feed. The gate had 2 openings under which a bucket mount was fastened to hold feed pails. Pre-weaning calves had access to 2, 8 L capacity pails containing their solid feed. Post-weaning these pails were replaced with 2, 20 L capacity pails, one contained solid feed and the other was filled with fresh water. During the pre-weaning phase 20 L pails were fastened to the rear corner of the pen for access to water. Pens were bedded with straw for the first week of life for added warmth and then switched to wood shavings thereafter, as per standard protocol at the research farm. Bedding was completely replaced twice weekly and replenished as needed.

3.2.2 Milk Feeding Procedure

Calves were offered acidified milk replacer daily at 0900 h from wk 1 through wk 7. The milk feeding apparatus consisted of an artificial teat (Peach Teats, Skellerup Industries Ltd., Woolston, New Zealand) mounted to the front gate of the pen, which was attached to a hose and one way valve ending in a bucket that was placed in front of each pen. The entire milk feeding apparatus was replaced and sanitized daily. The milk replacer fed contained 26% CP and 16% fat (Optivia Advantage Milk Replacer, Nutreco Canada Inc., Guelph, Canada). Fresh milk replacer was mixed daily as directed at a rate of 150 g/L. During mixing, prediluted 9.8% formic acid (The Acidified Milk Solution, NOD Apiary Products Ltd., Frankford, Canada) was added to the mixture to reduce pH to a range of 4.0 to 4.5 to prevent microbial growth.

Each calf was offered up to 12 L/d (1.8 kg DM) of milk replacer once per day for the first 38 d of life. Beginning on d 39 calves were offered decreasing amounts by 1 L/d (0.15 kg/d DM) to facilitate weaning. Thus, d 50 was the first day calves were no longer offered milk.

3.2.3 Treatments

Upon arrival at the research facility, calves were randomly assigned to 1 of 4 feeding treatments (Table 3.1): 1) a silage-based total mixed ration (**TMR**), 2) a textured dairy starter concentrate (Shur-Gain, Nutreco Canada Inc., Guelph, Canada) mixed with chopped grass hay (<2.5 cm) in a ratio of 85:15 (**MIX**), 3) the same concentrate and chopped hay offered as separate components (**SEP**), and 4) the same concentrate offered without hay (**CON**). The hay used for both the MIX and SEP diets was chopped using a New Holland 355 grinder-mixer (New Holland Inc., New Holland, USA) to pass through a 2.54 cm screen. Fresh feed was offered ad libitum and delivered at 1030 h daily. Fresh TMR was mixed by farm staff using a mixer wagon (Jaylor Mixer Model 4425, Jaylor Fabricating, East Garafraxa, Canada) and delivered to the calf facility daily. Before feeding TMR, a diluted monensin pellet (Diluted Rumensin Pellet, Shur-Gain, Nutreco Canada Inc., Guelph, Canada) was hand mixed into the ration at the recommended rate of 20 kg/tonne for consistency across treatments (as the concentrate also contained this). Chopped hay and concentrate for the MIX diet were mixed together by hand for each individual calf at the described ratio and fed out of 2 pails. The calves on the SEP treatment received that same ratio of components, but they were offered separately in 2 pails. In many commercial dairy operations calves are offered forage post-weaning, therefore, post-weaning (wk 8 to 12) all calves from the SEP and CON treatments were offered the MIX diet and calves on the TMR and MIX diets did not change feed types.

Orts were removed from pails prior to fresh feed delivery each day. Amount of feed provided was sufficient to result in >15% orts. Daily feed intake was determined by weighing daily offered feed and daily refusals for each individual calf.

3.2.4 Body Weight, Feed Sample Collection and Analysis

Calves were weighed upon arrival to obtain an initial BW using a calibrated digital floor scale (P2000 floor scale, Avery Weigh-Tronix, Pointe-Claire, Canada). Each calf was thereafter weighed twice weekly on 2 consecutive d at the same time of day to obtain accurate weekly BW values.

Samples of dietary treatments, feed components, and orts were taken on a weekly basis (d 4 of each wk) to determine accurate daily DMI measurements and nutrient analyses. In addition, fresh and orts samples were taken on d 4 and 5 of wk 7 for TMR and MIX calves only, and on d 4 and 5 of wk 9 and 11 for all calves to assess feed sorting. Each sample taken was frozen at -20°C until time of analysis.

Samples of fresh feed and orts taken for sorting analyses were analyzed by evaluating particle size distributions using a 3-screen Penn State Particle Separator (PSPS). This apparatus separates the feed sample into 4 fractions: >19 mm (long), <19, >8 mm (medium), <8, >1.18 mm (short), <1.18 mm (fine) (Kononoff et al., 2003). After separation with the PSPS system each fraction was dried in an oven at 55°C for 48 h. All other fresh feed samples taken were also oven-dried at 55°C for 48 h before being ground to pass through a 1-mm screen using a Wiley Mill (Arthur H. Thomas Co., Philadelphia, USA). Ground feed component samples were pooled together into 2 samples per replicate (wk 3-8 and wk 9-12), while ground fresh samples of each diet were pooled together into 3 samples per replicate (wk 3-5, wk 6-8, and wk 9-12). Pooled samples were sent to Cumberland Valley Analytical Services Inc. (Maugansville, USA) for analysis of DM (135°C; AOAC International, 2000: method 930.15), ash (535°C; AOAC International, 2000: method 942.05), ADF (AOAC International, 2000: method 973.18), NDF with heat-stable α-amylase and sodium sulfate (Van Soest et al., 1991), and CP (N x 6.25; AOAC International, 2000: method 990.03; Leco FP-528 Nitrogen Analyzer, Lecom St. Joseph, USA). Additionally non-fiber carbohydrate content was calculated as 100 – (% CP + % NDF + % fat + % ash) (NRC, 2001).

To asses rumen development in calves, blood BHBA concentration was measured (Brown et al., 2014) using a Precision Xtra meter (Abbott Diabetes Care, Saint Laurent, Canada; validated in cows by Iwersen et al., 2009) and blood ketone test strips (Abbott Diabetes Care) on d 7 of wk 3, 5, 7, 9, and 11. Tests were performed by drawing a very small amount of blood (< 1mL) from the coccygeal vein using a 23G needle and 1 mL syringe. A droplet of blood was placed on the test strip and the reader indicated results of blood BHBA concentration in mmol/L.

3.2.5 Calf Behaviour

Calf behaviour was recorded continuously for all calves in the second study replicate (n = 24 calves, 6 calves/treatment) using 8 colour video cameras (day/night camera, model no. WV-CP504; Panasonic, Osaka, Japan). Each camera was equipped with an F0.95/2.8 to 8 mm lens (Fujinon CCTV lens; Fuji, Tokyo, Japan). Video feed from all 8 cameras were available for recording and viewing on a digital video recorder (digital disk recorder, model no. WJ-HD616K; Panasonic). Video recordings were set at 15 images/s. Each camera was mounted approximately 2 m in front of the pens and 4 m from the floor of the barn. Each of the 24 pens had a camera capable of viewing the entire front gate of the pen where feed buckets and milk apparatuses were mounted. To facilitate night time viewing five red lights (100 W) were set on timers and spaced evenly between cameras to allow clear recording.

Calf behaviour was observed for 24 h/d on 2 consecutive d at the end of alternate weeks (d 6 and 7 of wk 3, 5, 7, 9, and 11) for all calves in the second block (n=24 calves). Due to technical issues with one of the cameras during wk 11, 2 calves did not have video recordings available for analysis. During the entirety of the study video was analyzed using instantaneous scans at 1-min intervals for milk-feeding and solid feed consumption (as validated by Miller-Cushon and DeVries, 2011b). Milk-feeding was defined as a calf having its mouth closed on the teat and with milk flowing through the hose. Solid feed consumption was defined as the calf's head lowered into the feed pail. Feeding time data was averaged across the 2 observation d to obtain an average daily feeding time per calf for each of the recorded weeks. Calves fed the SEP diet prior to weaning had feeding time values for both feeds separately, as well as total feeding time.

Rumination time was recorded by live observation on d 5, 6, and 7 of alternating weeks beginning on wk 3. On these days 1 min scans were performed for 1 h beginning at 1500 h and ending at 1600 h for a total of 60 observations per calf per day. This observation period was chosen based on the effectiveness of a similar time frame in measuring calf behaviour in a previous study by Eckert et al. (2015).

In addition to the collection of feeding behaviour, calves were fitted with electronic data loggers (HOBO Pendant G Data Logger, Onset, Pocasset, USA) for 7 d on a biweekly schedule that began at the start of wk 3 to record standing and lying behaviour (validated in calves by Bonk et al., 2013). Data was collected for daily standing and lying time as well as number of daily lying bouts. Loggers were secured to the rear leg using bandage tape (Vetrap Bandaging Tape, 3M, London, Canada) as per UBC AWP (2013).

3.2.6 Calculations and Statistical Analysis

Growth was measured as ADG during each week; ADG was calculated as the difference in BW for that week divided by 7 d. Gain-to-feed ratios was calculated by dividing the total BW gain in a given week by the total DM consumed that week. Feeding rate was calculated by dividing total feeding time by grams of solid feed DM consumed that day.

To test for feed sorting, the DMI of each fraction of the Penn State Particle Separator was calculated and expressed as a percentage of the predicted DMI of that fraction based on a sample of the fresh feed (Leonardi and Armentano, 2003). The predicted intake of each fraction was calculated as the product of the DMI of the total diet multiplied by the DM percentage of that fraction in the fresh feed. Values equal to 100% indicated no sorting, <100% indicated selective refusals (sorting against), and >100% indicated preferential consumption (sorting for). Sorting values were averaged to create one value per fraction per calf per week.

All data collected was summarized and analyzed by stage: pre-weaning (wk 1 – 5), weaning (wk 6, 7), and post-weaning (wk 8 - 12) and by wk within stage. Before any analysis was performed all data was tested for normality using the UNIVARIATE procedure of SAS (SAS Institute Inc., Cary, USA, 2013).

Data were analyzed using the MIXED procedure of SAS, treating week as a repeated measure. The model included the fixed effects of treatment, week and treatment by week interaction and the random effects of block and calf within block. Compound symmetry was selected as the variance-covariance matrix structure on the basis of best fit according to Schwarz's Bayesian information criterion. For the feed sorting data, to determine if sorting occurred, sorting activity for each fraction was tested for a difference from 100% by using the above mentioned mixed model. All values reported are least square means. Treatment differences were compared using the least-squares means procedure with the PDIFF option and the Tukey-Kramer adjustment. Significance was declared at $P \leq 0.05$, and tendencies were reported if $0.05 \leq P \leq 0.10$.

3.3 Results

Nutrient composition of the treatment diets are presented in Table 3.1. The TMR diet had a low DM content compared to the other diets (Table 3.1). Although DM was not consistent across treatments, the NFC, CP and ME levels of both TMR and MIX were similar. The TMR diet had much higher levels of ADF and NDF than both MIX and CON diets. The ME of the MIX diet was lower than that of the concentrate. The ME of the TMR was greater than ME of hay, although it was lower than that of the MIX and concentrate.

When measuring feed intake on an as-fed basis there was no difference between treatments ($P = 0.40$) in all 3 stages of the trial (Figure 3.1a). Although all calves showed an increase in DMI with age, in the pre-weaning phase, TMR calves showed a tendency for lower DM solid feed consumption than calves on the other 3 diets (Table 3.2; Figure 3.1b). During both the weaning and post-weaning stages, calves on the MIX, SEP and CON diets consumed more solid feed, on a DM basis, than calves fed TMR (Table 3.2). Calves offered hay and concentrate separately consumed 0.01 ± 0.002 kg/d of hay during the pre-weaning period and 0.05 ± 0.013 kg/d during the weaning period. There was no difference in concentrate intake for calves fed the CON and SEP diets in both the pre-weaning ($P = 0.91$) and weaning ($P = 0.99$) stages. Pre-weaning there was an interaction between treatment and week for milk replacer DMI (Table 3.2), likely reflecting week-to-week variation in milk consumption. Over the weaning phase milk replacer intake decreased over time (Table 3.2). Solid feed intake and total DMI showed an interaction of treatment and week during the weaning phase (Table 3.2). During wk 6 there was no treatment difference in DMI, however during wk 7 TMR calves had lower DMI than calves on the other diets ($P = 0.01$). During the post-weaning stage an interaction of treatment and week effect was present for DMI. In wk 8 and 9 TMR calves consumed less solid feed than calves on the MIX and SEP treatments, respectively ($P = 0.05$). Later in the post-weaning period, during wk 11 and 12 calves on all other treatments consumed more solid feed DM than TMR fed calves ($P = 0.03$).

There was no difference in ADG across treatments in the pre-weaning stage (Table 3.2). During this time ADG decreased for all treatments by calf age (Table 3.2). Calves fed the TMR diet showed lesser gains across the weaning period and the post-weaning stage (Table 3.2). While calves were being weaned, ADG decreased over time for all treatment groups (Table 3.2). There was no treatment difference in gain-to-feed ratio in the pre-weaning and post-weaning phase; however, gain-to-feed ratio decreased with calf age during both of these stages (Table 3.2). During weaning, calves on the TMR treatment tended to have a lower gain-to-feed ratio than calves on SEP and CON diets ($P = 0.08$). Calves fed the MIX diet had a better gain-to-feed ratio than TMR calves ($P = 0.01$).

During both the pre-weaning (34.2 ± 6.33 min/d; $P = 0.98$) and weaning (4.4 ± 0.69 min/d; $P = 0.89$) stages there was no difference in milk feeding time across treatments. There was also no treatment difference in rate of intake for milk replacer during the pre-weaning (47.4 ± 9.54 g/min; $P = 0.67$) or weaning (145.5 ± 21.40 g/min; $P = 0.94$) stages. Pre-weaning, there was no difference in feeding time of solid feed across treatments, although feeding time increased with calf age (Table 3.3). There was a trend for calves fed the TMR diet to eat solid feed slower compared to calves fed the CON diet. During the weaning phase, solid feed feeding time was greater for calves fed the TMR and MIX diets (Table 3.3). During this phase, feeding rate was lower for the TMR calves. Post-weaning, TMR calves showed the longest feeding time and the slowest feeding rate of all 4 treatment groups (Table 3.3). Throughout the study, there was no difference in lying time across treatments. Pre-weaning, all calves showed a decrease in lying time with age, however in the post-weaning stage calves showed an increase in lying time between wk 9 and 11 (Table 3.3). Frequency of lying bouts increased for all calves with age pre-weaning. Calves fed the TMR diet did, however, have fewer lying bouts/d in the post-weaning stage (Table 3.3). No differences between treatments in rumination time were evident in the pre-weaning and post-weaning stages (Table 3.3). Rumination time was higher for MIX calves than CON calves during the weaning stage. Rumination time increased with calf age during the pre-weaning stage (Table 3.3).

Calves fed the TMR diet did not exhibit sorting behaviour throughout the trial (Table 3.4). Calves fed the MIX diet, regardless of diet pre-weaning, sorted against fine particles in wk 9. In wk 11, all calves on the MIX diet no longer sorted against fine particles and began to sort for short particles (Table 3.4).

No difference ($P > 0.05$) in blood BHBA concentration (Figure 3.2) was observed during the pre-weaning (0.02 ± 0.015 mmol/L) and weaning stages (0.15 ± 0.050 mmol/L), although blood BHBA concentration increased linearly ($P = 0.03$) across this time period. There was a clear difference in post-weaning blood BHBA concentration (Figure 3.2); calves fed the TMR diet showed much higher blood BHBA level than calves fed the other diet (0.47 mmol/L vs 0.30 mmol/L; SE = 0.06; $P = 0.03$).

3.4 Discussion

For calves to experience a smooth transition from liquid feed (milk) to solid feed at weaning, it is crucial to avoid loss of BW at this time. The goal of the present study was to determine the optimal solid feeding strategy for minimizing the negative effects of weaning. This target was achieved by all calves fed only concentrate or a mixture of hay and concentrate, but calves fed a silage-based TMR failed to attain this goal.

Despite increasing slightly with age, intake of solid feed remained very low until milk reduction began. The steady increase in DMI beginning at the start of the weaning program on the third day of wk 6 and ending on the first day of wk 8 is similar to findings of other studies that implemented a gradual weaning program (Khan et al., 2007a,b; Sweeney et al., 2010). Feed type and method of presentation did not affect DMI or ADG in the pre-weaning phase, which was consistent with the findings of other studies feeding high milk levels (e.g. Khan et al., 2011). Differences in DMI were not significant until the beginning of the weaning period, when milk intake was gradually decreased. Calves fed TMR still showed comparable intakes in wk 6 but when milk continued to decrease during wk 7, the difference in DMI between this treatment and calves fed MIX, SEP, and CON became greater. The difference in DMI persisted into the post-weaning period when calves on the TMR treatment consumed approximately 1 kg/d less DM than calves on the other treatments, contrary to our hypothesis. While the TMR diet had a much lower DM content than the other diets, it also was high in NDF and ADF. Thus, prior to being able to meet nutritional needs from the TMR, calves on this diet likely felt full due to more rapid gut fill from the high moisture and fiber content of that feed (Drackley, 2008). It seems calves on the TMR diet were unable to achieve the same DMI as calves on all other treatments due the high moisture content of their feed, despite attempting to maximize nutrient intake as shown by similar feed intake across treatments on an as-fed basis. Due to the large difference in moisture content, even if diets were balanced by nutrient composition, calves offered TMR would have needed to consume approximately 75% more feed on an as-fed basis to attain the same level of

ME intake as calves fed the MIX diet during the post-weaning period. This level of intake would likely not be biologically possible. It follows, therefore, that the TMR calves did not show growth rates and DMI comparable to their MIX fed counterparts during weaning and afterwards primarily as a result of low DM and high fibre content of the feed offered.

Although previous studies have shown a positive effect of hay intake on overall DMI (Khan et al., 2011; Castells et al., 2012; Castells et al., 2015), this experiment showed no detriment or benefit to the inclusion of forage in the form of chopped hay in the diet. Differing results could be attributed to the level of milk offered, method of inclusion of the chopped hay or the type of hay offered in the current study. Calves in the study by Castells et al. (2012) were offered less milk, thus were consuming more solid feed prior to weaning than calves in the current study. Therefore, it is likely that differences in overall DMI were more pronounced in that previous study due to greater concentrate intake, results that may have been seen in the current study if the CON calves were fed only concentrate post-weaning. Both Khan et al. (2011) and Castells et al. (2012) offered hay separately for the entire trial, while this study provided hay separately from concentrate in the pre-weaning and weaning stages and then in a mixture with concentrate, post-weaning. The level of hay consumed in our study is comparable to the range of forage intake found by Castells et al. (2012). Throughout the pre-weaning and weaning stages, while SEP and CON calves were offered concentrate on its own, there was no difference in concentrate intake or overall DMI. This reinforces the evidence that offering hay to calves fed high levels of milk causes no detrimental effects on intake of concentrate, which is crucial for rumen development (Stobo et al., 1966).

Due to the much lower DM consumption of the calves fed the TMR diet, the ADG achieved by this treatment group was much lower than the ADG of calves fed MIX, SEP, and

CON diets from weaning time to the completion of the trial. A difference in ADG was likely not present in the pre-weaning phase as a result of a constant, high milk intake and low solid feed intake across all treatments, similar to findings of other studies feeding high levels of milk (e.g. Sweeney et al., 2010). The only difference in gain-to-feed ratio occurred during weaning when calves offered TMR showed lower gain-to-feed than all other calves. This difference is likely due to the change in primary nutrient source at this time; calves had to become more reliant on nutrients available from digestion of solid feed. The fermented forages included in the TMR may have been more difficult for calves to digest at this time (Drackley, 2008). However, it is likely that the lower DMI of calves fed TMR was a greater limiting factor in overall nutrient availability and growth in this study. It is interesting to note that calves on the TMR diet had a similar gain-to-feed ratio post-weaning, suggesting that the digestibility of the type of feed itself was likely not the cause of the lesser ADG. It follows that even though these calves were able to digest the feed presented, but were unable to achieve sufficient DMI for similar growth.

Longer feeding times for MIX and TMR calves during the weaning period was expected because calves fed these diets involuntarily consumed higher levels of forage, and thus had a more diluted nutrient source than the CON and SEP calves. Therefore, it follows that TMR and MIX calves would have a slower feeding rate at this transitional time. The TMR calves exhibited longer feeding times during both weaning and post-weaning stages, which could be attributed to their low DM feed and high fiber content. Greter et al. (2008) found that adding greater levels of straw to the ration increased NDF and ADF, while decreasing DMI and increasing daily feeding time in pre-pubescent heifers. Rumination time was not different between treatments during both the pre-weaning and post-weaning stages. However, during the weaning phase, rumination time was higher for MIX calves than CON calves, once again coinciding with their high level of forage consumption during the same time period compared to calves fed the CON diet. Although there was no treatment difference in total lying time there was a decrease in the number of lying bouts for TMR calves during the weaning period; we speculate that this activity relates to the increased time spent eating by the TMR-fed calves.

In both wk 9 and 11, calves fed the TMR diet (at 52% DM) showed no sorting behaviour. Although little previous research exists on feeding silage-based TMR to calves, sorting by adult dairy cows was lowered when fed a wet TMR (64% DM) compared to a dry TMR (80% DM: Leonardi et al., 2005). This may explain why calves fed the dry MIX diet (DM = 89.8 ± 0.8%), regardless of previous diet, exhibited some sorting behaviour in the post-weaning stage. These calves all sorted against fine particles in wk 9. Towards the end of the trial calves fed the MIX diet began to sort for short particles; a greater selection for short particles 3 wk after weaning may indicate a desire to consume more concentrate, the higher energy portion of the feed to support high growth demands in this stage (Drackley, 2008; Miller-Cushon and DeVries, 2011a). Although CON, SEP, and MIX calves were previously exposed to different feed treatments there was no difference in sorting behaviour of these calves post-weaning, contrary to the findings of Miller-Cushon et al. (2013c) who found that, when given the opportunity to sort the ration at this time, calves will continue to do so post-weaning.

Treatment had no effect on blood BHBA prior to weaning. All calves involved in the current study showed low BHBA levels during the pre-weaning stage, when consuming little solid feed, and experienced a large increase over the weaning period as feed intake rose sharply. Blood BHBA measurement has recently been used as an indicator of rumen development in dairy calves (Khan et al., 2011). Typically, grain-based calf starters are fed to increase solid feed fermentation for the production of higher levels of butyrate over the transition to solid feed in order to increase the development of ruminal papillae (Baldwin et al., 2004; Drackley 2008). An increase in BHBA has been shown to indicate a shift in source of nutrients from liquid feed to solids (Coverdale et al., 2004). Similar findings of BHBA increase with age and feed intake have been recorded in previous studies of rumen development around the weaning time (Quigley et al., 1992; Coverdale et al., 2004). In the study by Quigley et al. (1992) a decrease in BHBA and an increase in overall DMI were associated with the consumption of hay; however, in the current study all calves were fed hay post-weaning, so the effects of feeding hay on BHBA level are unclear. During the post-weaning phase, the BHBA level for TMR calves continued to increase, rather than plateauing as it did for MIX fed calves. It is possible that the butyrate levels of the fermented feed contributed to the increased blood BHBA levels in TMR calves. It would be speculative to comment in depth on the rumen development of these calves without further measures of rumen physiology. To date, there is no research on the effect of feeding silage on BHBA level in calves, thus this also requires further investigation.

3.5 Conclusions

These results suggest that pre-weaning solid feeding treatment has little effect on growth and intake of calves fed a high level of milk during this stage. However, difficulties arise during the weaning and post-weaning phases when calves fed TMR are faced with the challenge of high moisture content in their main solid feed source. Therefore, these results suggest that diets with high DM levels, which may include a limited amount of chopped forage, are advantageous to the developing ruminant around weaning time, while those diets high in moisture and fiber are not recommended.

3.6 Acknowledgments

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Table 3.1. Chemical composition of feed components and mixed rations (mean ± SE; DM basis).

Chemical composition[1]	Concentrate[2]	Mixed ration[3]	Hay[4]	TMR[5]
DM, %	90.3 ± 0.7	89.8 ± 0.8	88.3 ± 1.6	51.5 ± 3.1
NDF, % of DM	14.7 ± 0.40	21.6 ± 0.56	61.1 ± 0.57	31.7 ± 0.76
ADF, % of DM	6.5 ± 0.36	11.7 ± 0.57	38.6 ± 0.73	21.4 ± 0.88
NFC, % of DM	48.5 ± 1.48	46.1 ± 0.91	18.6 ± 0.59	40.4 ± 0.80
CP, % of DM	20.9 ± 0.68	18.0 ± 0.61	8.3 ± 0.34	15.2 ± 0.13
ME, Mcal/kg of DM	2.9 ± 0.03	2.7 ± 0.02	2.0 ± 0.02	2.5 ± 0.02

[1]Values were obtained from chemical analysis of feed samples.

[2]Dairy calf starter concentrate supplied by Rooney's Feeds (Iroquois, Canada) containing (on as-is basis): 36.5% corn, 28% calf starter supplement (Shur-Gain, Nutreco Canada Inc., Guelph, Canada), 20% rolled barley, 2.5% dilute monensin sodium, 2% molasses, 1% soybean oil.

[3]Contained, as a % of DM: 85% concentrate and 15% hay (chopped < 2.5 cm).

[4]Second-cut chopped grass hay.

[5]Contained, as a % of DM: 37% corn silage (chemical composition was: 6.7% CP, 37.3 % NDF, 50.6% NFC), 34% red clover haylage (20.2% CP, 43.0% NDF, 24.7% NFC), 16% high moisture corn (9.0% CP, 9.6% NDF, 75.6% NFC), 13% protein supplement (35.2% CP, 23.3% NDF, 16.3% NFC), 0.02% diluted monensin (Diluted rumensin pellets, Shur-Gain, Nutreco Canada Inc.).

Table 3.2. Intake and BW gain of calves during pre-weaning, weaning and post-weaning stages[1]

	Treatment				SE	*P*-value [4]		
	CON	MIX	SEP	TMR		T	W	T x W
Pre-weaning[2]								
Solid feed intake, kg/d	0.08	0.10[†]	0.09	0.03[†]	0.029	0.08	<0.001	0.11
Milk replacer intake, kg/d	1.41	1.43	1.41	1.38	0.092	0.95	<0.001	0.01
Total DMI, kg/d	1.45	1.49	1.46	1.40	0.087	0.73	<0.001	0.27
ADG, kg/d	1.1	1.1	1.1	1.0	0.07	0.16	<0.001	0.98
Gain-to-feed ratio, kg/kg	0.76	0.79	0.75	0.67	0.102	0.63	0.02	0.78
Weaning[2]								
Solid feed intake, kg/d	0.46	0.50	0.52	0.19	0.094	0.002	<0.001	0.003
Milk replacer intake, kg/d	0.98	1.00	1.00	0.99	0.038	0.91	<0.001	0.85
Total DMI, kg/d	1.43	1.49	1.51	1.18	0.102	0.009	<0.001	0.01
ADG, kg/d	0.4[a]	0.5[a]	0.5[a]	0.2[b]	0.09	0.001	<0.001	0.20
Gain-to-feed ratio, kg/kg	0.28[a]	0.31[a]	0.30[a]	0.07[b]	0.129	0.001	<0.001	0.08
Post-weaning[3]								
Solid feed intake, kg/d	2.68	2.67	2.87	1.78	0.240	<0.001	<0.001	0.02
ADG, kg/d	1.2[a]	1.2[a]	1.2[a]	0.7[b]	0.08	<0.001	0.18	0.57
Gain-to-feed ratio, kg/kg	0.50	0.62	0.50	0.43	0.138	0.40	<0.001	0.72

[1]Data are averaged by week for each calf per treatment (n=12/treatment)

[2]CON = calves provided concentrate only, MIX = calves provided mixture of 85% concentrate and 15% chopped hay, SEP = calves provided concentrate and chopped hay in separate buckets, TMR = calves provided a silage-based TMR.

[3]CON, MIX, SEP = calves provided mixture of 85% concentrate and 15% chopped hay, TMR = calves provided a silage-based TMR

[4]T = effect of treatment; W = effect of week, T x W = interaction between treatment and week.

[a,b] treatment means within row with different superscripts differ ($P < 0.05$)

[†] treatment means within row with same superscripts differ ($P < 0.10$)

Table 3.3. Calf behaviour during pre-weaning, weaning and post-weaning stages[1].

Item	Treatment					*P-value*[4]		
	CON	MIX	SEP	TMR	SE	T	W	TxW
Pre-weaning[2]								
Solid feeding time, min/d	14.3	18.8	15.6	14.8	4.82	0.79	<0.001	0.91
Rate of intake, g/min	7.9[†]	4.7	5.4	1.8[†]	2.80	0.08	0.85	0.36
Lying time, min/d	1063.0	1065.5	1084.1	1077.1	19.97	0.63	0.002	0.43
Lying bouts/d	20.4	20.9	21.7	21.8	1.54	0.72	0.04	0.32
Rumination time min/h	5.0	5.4	7.5	5.9	2.42	0.60	<0.001	0.29
Weaning[2]								
Feeding time, min/d	87.5[b]	155.9[a]	113.9[b]	138.3[a,]	20.97	0.02	-	-
Rate of intake, g/min	9.4[a,†]	5.4[a,b,†]	7.3[a]	2.5[b]	1.52	0.002	-	-
Lying time, min/d	1033.1	1032.2	1041.2	1036.9	18.39	0.96	-	-
Lying bouts/d	17.5	16.4	17.5	16.9	1.00	0.62	-	-
Rumination time min/h	6.3[b]	17.8[a,†]	11.1[b,†]	11.9[a,b]	2.80	0.002	-	-
Post-weaning[3]								
Feeding time, min/d	194.4[b]	208.4[b]	180.5[b]	307.5[a]	22.60	<0.001	0.29	0.84
Rate of intake, g/min	13.0[a]	13.2[a]	17.0[a]	5.9[b]	2.74	0.002	<0.001	0.47
Lying time, min/d	1061.3	1044.8	1055.2	1015.9	23.58	0.13	0.003	0.49
Lying bouts/d	16.9[a]	16.9[a]	17.8[a]	14.4[b]	1.14	<0.001	0.32	0.56
Rumination time min/h	18.3	17.8	17.4	19.5	3.32	0.87	0.71	0.33

[1]Data are averaged by week for each calf per treatment (n=6/treatment; measured on alternate weeks only i.e. wk 3, 5, 7, 9, 11)

[2] CON = calves provided concentrate only, MIX = calves provided mixture of 85% concentrate and 15% chopped hay, SEP = calves provided concentrate and chopped hay in separate buckets, TMR = calves provided a lactating cow total mixed ration.

[3] CON, MIX, SEP = calves provided mixture of 85% concentrate and 15% chopped hay, TMR = calves provided a lactating cow total mixed ration.

[4]T = effect of treatment; W = effect of week, T x W = interaction between treatment and week.

[a,b] treatment means within row with different superscripts differ ($P < 0.05$)

[†] treatment means within row with same superscripts differ ($P < 0.10$)

Table 3.4. Effect of different feed type treatments[1] on sorting (%) of calves[2] fed TMR and MIX rations post-weaning.

	Week 9				Week 11					*P*-value [4]		
Sorting of particle size fraction, %[3]	CON	MIX	SEP	TMR	CON	MIX	SEP	TMR	SE	T	W	T x W
Long	-	-	-	87.2	-	-	-	92.2	9.47	-	0.49	-
Medium	101.2	100.0	102.7	98.9	91.3[a,b]	85.7[*,b]	88.9[a,b,†]	99.2[a,†]	5.21	0.19	<0.001	<0.001
Short	101.3	103.7	100.3	103.5	102.9[*,a,b]	105.2[*,a]	103.9[*,a,b]	100.3[b]	1.85	0.06	0.15	0.001
Fine	80.1[*,b]	81.5[*,b]	80.6[*,b]	102.6[a]	97.0	96.3	94.8	103.8	3.22	<0.001	<0.001	0.03

[1]Treatment (T): MIX = calves provided mixture of 85% concentrate and 15% chopped hay, CON = calves previously provided concentrate only, fed MIX diet post-weaning, SEP = calves previously offered concentrate and chopped hay separately, fed MIX diet post-weaning, TMR = calves provided a lactating cow total mixed ration.

[2]Data are averaged by week for each calf per treatment (n = 12/treatment)

[3]Sorting % = 100 x (actual particle size fraction DM intake/ predicted particle size fraction DM intake). Values equal to 100% indicate no sorting, <100% indicate selective refusals (sorting against), and >100% indicate preferential consumption (sorting for). Particle size determined by Penn State particle separator, which separates the particles in 4 fractions: long (>19 mm), medium (< 19, >8 mm), short (<8, >1.18 mm), and fine (<1.18 mm).

[4] Difference in sorting values from 100%: * $P \leq 0.05$

[a,b] treatment means within row with different superscripts differ ($P < 0.05$)

[†] treatment means within row with same superscripts differ (P < 0.10)

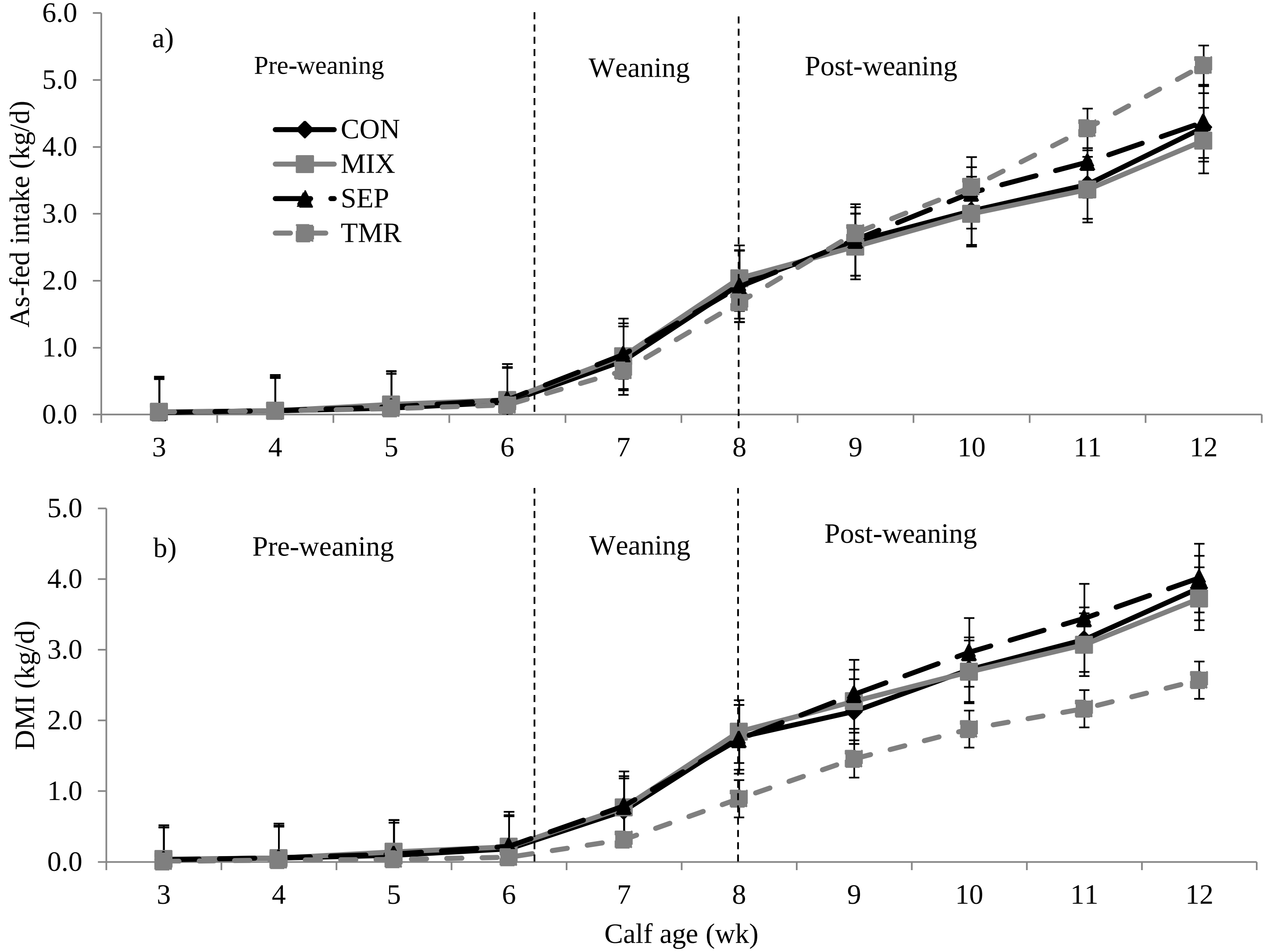

Figure 3.1. Mean (± SE) weekly as-fed intake (a) and DMI intake (b). Values are shown separately for calves fed concentrate only pre-weaning (CON; n=12), calves fed a mix of concentrate and chopped hay in a ratio of 85:15 (MIX; n=12), calves fed chopped hay and concentrate in separate pails (SEP; n=12), and calves fed a silage-based total mixed ration (TMR; n=12). All calves fed MIX, SEP, or CON fed MIX diet post-weaning (wk 8 to wk 12).

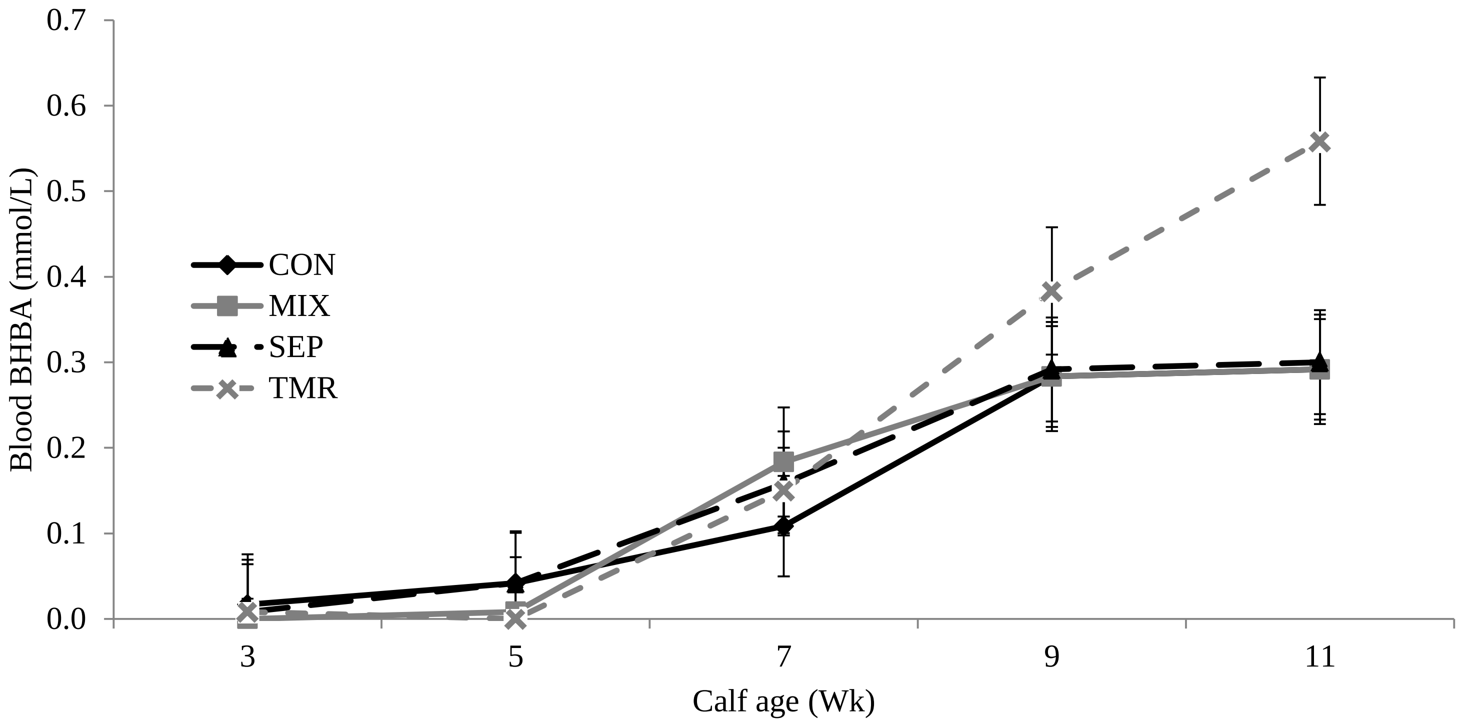

Figure 3.2. Mean (± SE) blood BHBA concentration of calves. Blood samples (<1 mL) were taken from the coccygeal vein. Values are results of test using Precision Xtra meter in mmol/L. Samples taken on d 7 of each alternate wk.

CHAPTER 4: GENERAL DISCUSSION

4.1 Important Findings

Previous research has established that feeding accelerated milk programs and providing palatable solid feed that promotes intake is important for calf growth and well-being (Jasper and Weary, 2002; Khan et al., 2011), but there is a paucity of information on the time budgets of these calves and the effects of offering forage to calves fed high levels of milk. The pre-weaning time budgets of calves in our first study (Chapter 2) changed in response to the end of milk feeding. As hypothesized, in both Chapter 2 and 3, calves increased solid feed intake with age and decreased milk intake over the pre-weaning and weaning period. This increase in solid feed consumption was accompanied by an increase in both feeding time and feeding rate for all calves. However, in Chapter 2, calves housed in pairs consumed more feed, showed greater feeding time and faster feeding rates than calves housed individually, similar to results of Chua et al. (2002). We hypothesize that social facilitation of feeding behaviour played a role in the expression of solid feeding behaviour of pair-housed calves prior to weaning, as calves were all paired post-weaning and differences were no longer present. In Chapter 3, calves fed TMR and the mixed diet had longer feeding times, while the TMR-fed calves also had slower feeding rates until the end of the study. From these findings, we speculate that since TMR-fed calves consumed a diet higher in fibre than calves fed the other diets in Chapter 3, feeding time increased post-weaning, as shown previously in older heifers by Greter et al. (2008).

Regardless of housing or feed presentation, to accommodate higher nutrient intake requirements, calves increased their feeding time and decreased lying time over the course of the weaning period, as expected in Chapter 2 and 3. Individually-housed calves, in Chapter 2, showed a disruption in lying behaviour on the day of mixing and showed altered feeding behaviour during the entire post-weaning week. These calves increased daily feeding time and began spending more time feeding in the early morning hours when compared to calves pair-housed from birth. It is likely that previously individually-housed calves were unaccustomed to the sharing of resources (i.e. feed, pen), and thus were forced to make adjustments like altered feeding patterns and a short term decrease in lying time. In Chapter 3 we observed that TMR-fed calves made adjustments post-weaning in response to transitioning from liquid to solid feed, while consuming a low DM, high fibre diet, with longer feeding times, slower feeding rates and fewer lying bouts.

In our second study (Chapter 3), feed type and method of presentation did not have an effect on solid feed intake and growth of calves prior to weaning. Calves offered concentrate with the provision of chopped grass hay showed no improvement on total solid feed consumption and growth rates, contrary to what we expected. Our results show that offering supplementary forage does not negatively affect the growth of dairy calves fed on accelerated milk feeding programs. Previous research has shown increased overall feed intake by offering forage to calves (Khan et al., 2011; Castells et al., 2012), although there seems to be a large variance in effect of forage feeding on overall intake in response to type of forage offered. An improvement in rumen development by increasing ruminal pH (Thomas and Hinks, 1982) and promoting development of the muscular rumen wall (Tamate et al., 1962) have been shown in previous studies of forage feeding to calves. Many of these studies feed forages of varying types and particle sizes, presenting forages separately or mixed with grains, making it difficult to compare results across studies. The current research supports feeding chopped grass hay alongside, or mixed with concentrate, to calves on accelerated milk feeding programs around weaning time due to the high DM content and high nutrient density of these feeds.

To our knowledge, the experiment in Chapter 3 is the first study to feed a silage-based TMR to weaning age calves and to show that calves fed this TMR prior to weaning did not experience a smooth transition from milk to solid feed. Contrary to our hypothesis, calves on the TMR diet had low DMI levels due to the higher moisture and fibre content of their feed, and thus were unable to consume sufficient quantities of feed to achieve comparable growth to calves fed the chopped hay and concentrate diet. Interestingly, calves offered TMR consumed the same level of feed on an as-fed basis throughout the study, indicating that these calves struggled to attain high DMI. However, despite a 1 kg difference in DMI post-weaning, there was no treatment difference in gain-to-feed ratio, indicating that digestibility of the feed was not the limiting factor in the growth of TMR fed calves. Therefore, we hypothesize that calves consuming TMR from a young age are limited by the feed's high moisture and fibre content and the resultant gut fill rather than digestibility of the fermented feed.

In both Chapter 2 and Chapter 3, blood BHBA concentration increased with age and solid feed intake, in agreement with previous research (Quigley et al., 1992; Coverdale et al., 2004). Calves fed TMR in Chapter 3 showed a greater increase in blood BHBA post-weaning despite consuming less solid feed than calves fed the mixed diet. We hypothesize that the fermented feed in the TMR diet could have caused an increased production of butyrate in the rumen of the TMR-fed calves resulting in an increase in blood BHBA. Despite this, the collective results of our studies provide further evidence for use of blood BHBA as a good indicator of DMI (of concentrate and dry forage) in calves.

4.2 Future Research

The studies presented in this thesis demonstrate there is more investigation to be done in relation to the housing management and feed type provision for dairy calves around the weaning period. Several questions may be raised from the analysis of our results. Although there was a benefit of pairing calves in terms of early solid feed consumption in Chapter 2, the best time to pair young calves is still unclear. Even though individually-housed calves in our study showed a quick recovery to the effect of a new partner on lying time, during the course of our study these calves did not return to their previous, more evenly dispersed feeding patterns. Thus, if calves are not paired from birth, further investigation is required to determine the best time to introduce calves into a group to have the least impact on behaviour. It would also be beneficial for future studies to observe daily activities of calves and movement around the pen, as data loggers are useful for determining postures, but do not provide insight to actions of calves when they are standing, this would provide further understanding of daily activities of calves, that may include behaviours such as play or standing idly, as a result of grouping.

The types of solid feeds that may be offered to young calves are numerous. When forage is considered, the options are even greater. With many studies focusing on different types of forages and various inclusion rates in the diet, it is difficult to determine what is best. Previous research has examined forage type and inclusion in the diet (Coverdale et al., 2004; Suárez et al., 2007), but rarely offer components separately (Castells et al., 2012) or to calve fed high levels of milk (Khan et al., 2011). Future research should be focused on comparing intake and performance of calves on accelerated milk programs offered different types of forages with a separate source of concentrate to determine preferred levels of forage intake without forcing calves to consume a pre-determined ratio of forage to concentrate. While this type of study has been conducted with calves fed restrictive amounts of milk (Castells et al., 2012), we now have evidence that these calves do not consume forage at the same levels as calves on accelerated milk programs. Although our study tested two different types and two different presentations of forage diets, future research on other types of forage in high milk-fed calves is necessary for a better understanding of which feed type is more beneficial to the young calf.

While calves immediately after weaning could not consume sufficient TMR for comparable growth, an appropriate time to introduce this feed into the diet is still unknown. The original evidence for the negative effects of feeding fermented feed to calves younger than 6 months of age is largely anecdotal (Drackley, 2008); therefore, scientific evidence in needed to determine at what point feeding TMR can begin. Though the previous interpretation was that the fermentation of the feed prevented proper digestion in the under-developed rumen, in Chapter 3, it is demonstrated that the main source of difficulty for the calves fed TMR is the moisture content. The TMR fed was 52% DM, thus due to the lack of treatment difference in gain-to-feed post weaning, we expected that feeding drier TMR would increase DMI and increase ADG in calves of a similar age. Feeding dry TMR to younger calves would provide a great benefit to the producer by decreasing feed and labor costs, thus future research into this type of feed for young calves is required.

In Chapter 3 we measured BW weekly; however, to accurately measure the performance of calves on varying feed programs it would be beneficial to record daily BW during the weaning period to better analyze growth at this crucial time. Even when calves are fed on gradual weaning programs, they do not gain weight at the same rate as they do pre-weaning when milk reduction begins (Sweeney et al., 2010), thus it is important to take daily measures over this time to determine at what point calves begin to have difficulty maintaining pre-weaning weight gain.

In addition, weight gain can be expected to be more variable from day-to-day during this time of transition, due to decreasing amounts of milk available and daily body weights would help account for this day-to-day variability.

Lying behaviour is still largely underrepresented in the current research of dairy calf rearing. With the recent advancement of the HOBO data logger for use in calves (Bonk et al., 2013), this measure has become easy to use and can provide more information on the time budgets of dairy calves from birth to beyond weaning. A decrease in lying time could indicate discomfort or stress, since lying down has been shown to be more important to dairy cattle than feeding after a period of deprivation (Munksgaard et al., 2005). Thus, it would be beneficial to the calf research area to have a measure of lying time per day for different weaning protocols to determine which weaning procedure is less disruptive to calves.

Rumination time in both Chapter 2 and 3 were recorded by live observation for 1 hr/d. In Chapter 2 we speculated that since calves were still spending large amounts of time consuming solid feed during our observation time, from 1200 to 1300 h, this time period did not allow us to determine treatment differences. As a result of decreased rumination time from pre-weaning to post-weaning, we can likely conclude that the observation time was not ideal, based on biological logic. Our observation period in Chapter 3 was later in the day, from 1500 h to 1600 h, and showed marked differences in calves fed forage mixed with concentrate and calves fed only forage during weaning time. Thus, it is likely that the observation period used in that study provides a more accurate measure of rumination behaviour than the period used in Chapter 2. Due to the inconvenience of 24-hr live observation, the most accurate measure would include an automated system of collecting rumination time from young calves. Unfortunately, the rumination collars validated for use in adult cattle by Schirmann et al. (2009) have been shown to be ineffective in dairy calves due to their smaller size (Burfeind et al., 2011). Thus, further research is required to develop an automatic means of measuring rumination in dairy calves.

4.3 Implications

There are several ways in which our research may be beneficial for calf rearing programs. While individually housing calves may be convenient for some producers that use calf hutches to house calves, pairing calves not only reduces labour required per calf, but, our results show that calves housed in pairs consume greater solid feed prior to weaning, thus providing an advantage over calves housed-individually. These calves seem to show a better transition from liquid to solid feed by not only increasing their daily feed intake, but also by altering feeding patterns.

Our findings show that despite previous beliefs that feeding forage would limit concentrate intake in calves, our research shows no detriment to overall feed intake with the inclusion of forage. Chopped hay can easily be fed to calves on accelerated milk feeding programs to promote rumen development. However, silage-based TMR is not suitable for calves during weaning, and shortly thereafter, due to high moisture and fibre content, preventing calves from consuming sufficient dry matter. Our results imply that feeding a silage-based TMR at a young age is detrimental for growth of calves during weaning and in the following weeks. This effect on growth does not seem to be a result of digestibility; therefore, even though it is palatable and digestible for calves of this age, it is not the best solid feed option. A more appropriate feeding strategy for calves fed high levels of milk at weaning time, based on our research, would include chopped grass hay and concentrate in a mixture or as separate components.

CHAPTER 5: REFERENCES

AOAC International. 2000. Official Methods of Analysis. 17th ed. Vol. 1. AOAC Int., Arlington, Virginia.

Appleby, M., D. Weary, and B. Chua. 2001. Performance and feeding behavior of calves on ad libitum milk from artificial teats. Appl. Anim. Behav. Sci. 74:191–201.

Babu, L. K., H. N. Pandey, and A. Sahoo. 2004. Effect of individual versus group rearing on ethological and physiological responses of crossbred calves. Appl. Anim. Behav. Sci. 87:177–191.

Bach, A., A. Gimenez, J. L. Juaristi, and J. Ahedo. 2007. Effects of physical form of a starter for dairy replacement calves on feed intake and performance. J. Dairy Sci. 90:3028–3033.

Baldwin, R. L. VI, K. R. McLeod, J. L. Klotz, and R. N. Heitmann. 2004. Rumen development, intestinal growth and hepatic metabolism in the pre- and post-weaning ruminant. J. Dairy Sci. 87(E Suppl.): E55-E65.

Bar-Peled, U., B. Robinzon, E. Maltz, H. Tagari, Y. Folman, I. Bruckental, H. Voet, H. Gacitua, and A. R. Lehrer. 1997. Increased weight and effects on production parameters of Holstein heifer calves that were allowed to suckle from birth to six weeks of age. J. Dairy Sci. 80:2523-2528.

Beharka, A. A., T. G. Nagaraja, J. L. Morrill, G. A. Kennedy, and R. D. Klemm. 1998. Effects of form of the diet on anatomical, microbial, and fermentative development of the rumen of neonatal calves. J. Dairy Sci. 81:1946–55.

Bøe, K. E. and G. Færevik. 2003. Grouping and social preferences in calves, heifers and cows. Appl. Anim. Behav. Sci. 80:175-190.

Bonk, S., O. Burfeind, V. S. Suthar and W. Heuwieser. 2013. Technical note: Evaluation of data loggers for measuring lying behavior in dairy calves. J. Dairy Sci. 96:3265-3271.

Brown, H. E., E. C. Eckert, M. A. Steele, T. J. DeVries, and K. E. Leslie. 2014. An evaluation of a calf-side betahydroxybutyrate test in dairy calves fed a high plane of nutrition and weaned at six versus eight weeks of age. J. Dairy Sci. E-Suppl. 1 97:312.

Burfeind, O., K. Schirmann, M. A. G. von Keyserlingk, D. M. Veira, D. M. Weary, and W. Heuwieser. 2011. Technical note: Evaluation of a system for monitoring rumination in heifers and calves. J. Dairy Sci. 94:426-430.

Camiloti, T.V., J. A. Fregonesi, M. A. G. von Keyserlingk, and D. M. Weary. 2012. Short communication: Effects of bedding quality on lying behavior of dairy calves. J. Dairy Sci. 95:3380-3383.

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.

Castells, L., A. Bach, and M. Terré. 2015. Short- and long-term effects of forage supplementation of calves during the preweaning period on performance, reproduction, and milk yield at first lactation. J. Dairy Sci. 98:1-6.

CCAC (Canadian Council on Animal Care). 2009. CCAC Guidelines on the Care and Use of Farm Animals in Research, Teaching and Testing. Canadian Council on Animal Care. Ottawa, ON, Canada

Chua, B., E. Coenen, J. van Delen, and D. M. Weary. 2002. Effects of pair versus individual housing on the behavior and performance of dairy calves. J. Dairy Sci. 85:360–364.

Clarke R. T. J. and C. S. W. Reid. 1974. Foamy bloat of cattle: A Review. J. Dairy Sci. 57:753-785.

Costa, J. H. C., R. R. Daros, M.A.G. von Keyserlingk, and D.M. Weary. 2014. Complex social housing reduces food neophobia in calves. J. Dairy Sci. 97:7804-7810.

Coverdale, J. A., H. D. Tyler, J. D. Quigley, and J. A. Brumm. 2004. Effect of various levels of forage and form of diet on rumen development and growth in calves. J. Dairy Sci. 87:2554–2562.

Day, M. L., K. Imakawa, A. C. Clutter, P. L. Wolfe, D. D. Zalesky, M. K. Nielsen, and J. E. Kinder. 1987. Suckling behavior of calves with dams varying in milk production. J. Anim. Sci. 65:1207–1212.

De Passillé, A. M. B., J. H. M. Metz, P. Mekking, and P. R. Wiepkema. 1992. Does drinking milk stimulate sucking in young calves? Appl. Anim. Behav. Sci. 34:23-36.

De Passillé, A. M., R. Christopherson, and J. Rushen. 1993. Nonnutritive sucking by the calf and postprandial secretion of insulin, CCK, and gastrin. Physiol. Behav. 54:1069–1073.

De Passillé, A.M., T.F. Borderas, and J. Rushen. 2011. Weaning age of calves fed a high milk allowance by automated feeders: Effects on feed, water, and energy intake, behavioral signs of hunger, and weight gains. J. Dairy Sci. 94:1401-1408.

De Passillé, A. M. and J. Rushen, 2012. Adjusting the weaning age of calves fed by automated feeders according to individual intakes of solid feed. J. Dairy Sci. 95:5292-5298.

De Paula Vieira, A., A. M. de Passillé, and D. M. Weary. 2012. Effects of the early social environment on behavioral responses of dairy calves to novel events. J. Dairy Sci. 95:5149-5155.

De Paula Vieira, A., V. Guesdon, A. M. de Passillé, M. von Keyserlingk, and D. Weary. 2008. Behavioral indicators of hunger in dairy calves. Appl. Anim. Behav. Sci. 109:180–189.

De Paula Vieira, A., M. A. G. von Keyserlingk, and D. M. Weary. 2010. Effects of pair versus single housing on performance and behavior of dairy calves before and after weaning from milk. J. Dairy Sci. 93:3079–3085.

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.

Diaz, M. C., M. E. Van Amburgh, J. M. Smith, J. M. Kelsey, and E. L. Hutten. 2001. Composition of growth of Holstein calves fed milk replacer from birth to 105-kilogram body weight. J. Dairy Sci. 84:830‑842.

Drackley, J. K. 2008. Calf nutrition from birth to breeding. Vet. Clin. North Am. Food Anim. Pract. 24:55–86.

Duve, L. R., D. M. Weary, U. Halekoh, and M. B. Jensen. 2012. The effects of social contact and milk allowance on responses to handling, play, and social behavior in young dairy calves. J. Dairy Sci. 95:6571–81.

Eckert, E., H. Brown, K. E. Leslie, T. J. DeVries, and M. Steele. 2015. Weaning age impacts growth, feed intake, gastrointestinal development and behavior of Holstein calves fed an elevated plane of nutrition during the pre-weaning stage. J. Dairy Sci. in press.

Ellis, J.A., S.P. Gow, S. Mahan, and R. Leyh. 2013. Duration of immunity to experimental infection with bovine respiratory syncytial virus following intranasal vaccination of young passively immune calves. Journal of the American Veterinary Medical Association. 243(11):1602-1608.

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.

Hamada, T., S. Maeda, and K. Kameoka. 1976. Factors influencing growth of rumen, liver, and other organs in kids weaned from milk replacers to solid foods. J. Dairy Sci. 59:1110-1118.

Hammell, K. L., J. H. M. Metz, and P. Mekking. 1988. Sucking behavior of dairy calves fed milk ad libitum by bucket or teat. Appl. Anim. Behav. Sci. 20:275–285.

Hammon, H. M., G. Schiessler, A. Nussbaum, and J. W. Blum. 2002. Feed intake patterns, growth performance, and metabolic and endocrine traits in calves fed unlimited amounts of colostrum and milk by automate, starting in the neonatal period. J. Dairy Sci. 85:3352–62.

Hänninen, L., A. M. de Passillé, and J. Rushen. 2005. The effect of flooring type and social grouping on the rest and growth of dairy calves. Appl. Anim. Behav. Sci. 91:193‑204.

Herskin, M. S., L. Munksgaard, and J. Ladewig. 2004. Effects of acute stressors on nociception, adrenocortical responses and behaviour of dairy cows. Physiol. Behav. 83:411-420.

Hill, T. M., H. G. Bateman, J. M. Aldrich, and R. L. Schlotterbeck. 2008. Effects of the amount of chopped hay or cottonseed hulls in a textured calf starter on young calf performance. J. Dairy Sci. 91:2684–2693.

Hill, T. M., H. G. Bateman II, J. M. Aldrich, J. D. Quigley, and R. L. Schlotterbeck. 2013. Short communication: Intesive measurements of standing time of dairy calves housed in individual pens within a naturally ventilated, unheated nursery over different periods of the year. J. Dairy Sci. 96:1811-1814.

Iwersen, M., U. Falkenberg, R. Voigtsberger, D. Forderung and W. Heuwieser. 2009. Evaluation of an electronic cowside test to detect subclinical ketosis in dairy cows. J. Dairy Sci. 92:2618-2624.

Jasper, J. and D. M. Weary. 2002. Effects of ad libitum milk intake on dairy calves. J. Dairy Sci. 85:3054–3058.

Jasper, J., M. Budzynska, and D. M. Weary. 2008. Weaning distress in dairy calves: Acute behavioral responses by limit-fed calves. Appl. Anim. Behav. Sci. 110:136‑143.

Jensen, M. B., K. S. Vestergaard, C. C. Krohn, and L. Munksgaard.1997. Effect of single versus group housing and space allowance on responses of calves during open-field tests. Appl. Anim. Behav. Sci. 54:109‑121.

Jensen, M. B., K. S. Vestergaard, and C. C. Krohn. 1998. Play behavior in dairy calves kept in pens: The effect of social contact and space allowance. Appl. Anim. Behav. Sci. 56:97‑108.

Jensen, M. B. 2004. Computer-controlled milk feeding of dairy calves: the effects of number of calves per feeder and number of milk portions on use of feeder and social behavior. J. Dairy Sci. 87:3428–3438.

Jensen M. B. and L. E. Larsen. 2014. Effects of level of social contact on dairy calf behavior and health. J. Dairy Sci. 97:5035-5044.

Jensen, M., B., L. R. Duve, and D. M. Weary. 2015. Pair housing and enhanced milk allowance increase play behavior and improve performance in dairy calves. J. Dairy Sci. 98:2568-2575.

Kehoe, S. I., C. D. Dechow, and A. J. Heinrichs. 2007. Effects of weaning age and milk feeding frequency on dairy calf growth, health and rumen parameters. Livest. Sci. 110:267‑272.

Kertz, A. F., L. R. Prewitt, and J. P. Everett Jr. 1979. An early weaning calf program: Summarization and review. J. Dairy Sci. 62:1835-1843.

Kertz, A. F., L. F. Reutzel, and J. H. Mahoney. 1984. Ad libitum water intake by neonatal calves and its relationship to calf starter intake, weight gain, feces score, and season. J. Dairy Sci. 67:2964-2969.

Key, C. and R. M. McIver. 1980. The effects of maternal influences on lambs: breed-differences in grazing, resting and courtship behavior. Appl. Anim. Ethol. 6:33‑48.

Khan, M. A., H. J. Lee, W. S. Lee, H. S. Kim, K. S. Ki, T. Y. Hur, G. H. Suh, S. J. Kang and Y. J. Choi. 2007b. Structural growth, rumen development, and metabolic and immune responses of Holstein male calves fed milk through step-down and conventional methods. J. Dairy Sci. 90:3376-3387.

Khan, M.A., H. J. Lee, W. S. Lee, H. S. Kim, S. B. Kim, K. S. Ki, J. K. Ha, H. G. Lee, and Y. J. Choi. 2007a. Pre- and postweaning performance of Holstein female calves fed milk through step-down and conventional methods. J. Dairy Sci. 90:876-885.

Khan, M. A., D. M. Weary, and M. A. G. von Keyserlingk. 2011a. Hay intake improves performance and rumen development of calves fed higher quantities of milk. J. Dairy Sci. 94:3547–3553.

Khan, M. A., D. M. Weary, and M. A. G. von Keyserlingk. 2011b. Invited review: Effects of milk ration on solid feed intake, weaning, and performance in dairy heifers. J. Dairy Sci. 94:1071–1081.

Kononoff, P. J., A. J. Heinrichs, and D. R. 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.

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., F. Giannico, and L. E. Armentano. 2005. Effect of water addition on selective consumption (sorting) of dry diets by dairy cattle. J. Dairy Sci. 88:1043-1049.

Maynard, L. A. and L.C. Norris. 1923. A system of rearing dairy calves with limited use of milk. J. Dairy Sci.6:483‑499.

Mench, J. A., J. C. Swanson, and W. R. Stricklin. 1990. Social stress and dominance among group members after mixing beef cows. Can. J. Anim. Sci.70:345-354.

Miller-Cushon, E. K., R. Bergeron, K. E. Leslie, T. J. DeVries. 2013a. Effect of milk feeding level on development of feeding behavior in dairy calves. J. Dairy Sci. 96:551-564.

Miller-Cushon, E. K., R. Bergeron, K. E. Leslie, G.J. Mason, and T. J. DeVries. 2013b. Effect of early exposure to different feed presentations on feed sorting of dairy calves. J. Dairy Sci. 96:4624-4633.

Miller-Cushon, E. K., R. Bergeron, K. E. Leslie, G. J., Mason, and T. J. DeVries. 2013c. Effect of feed presentation on feeding patterns of dairy calves. J. Dairy Sci. 96:7260-7268.

Miller-Cushon, E. K., R. Bergeron, K. E. Leslie, G. J. Mason, and T. J. DeVries. 2014. Competition during the milk-feeding stage influences the development of feeding behavior of pair-housed calves. J. Dairy Sci. 97:6450-6462.

Miller-Cushon, E. K. and T. J. DeVries. 2011a. 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. 2011b. Technical Note: Validation of methodology for characterization of feeding behavior in dairy calves. J. Dairy Sci. 94:6103-6110.

Miller-Cushon, E. K. and T. J. DeVries. 2015. Development and expression of dairy calf feeding behaviour. Can. J. Anim. Sci. cjas-2014-163, in press.

Miller-Cushon, E. K. and T. J. DeVries. Impact of social housing on the development of feeding behavior of dairy calves. 30 pp submitted to the Journal of Dairy Science on May 26, 2015. JDS-15-9869.

Mirza, S. N. and F. D. Provenza. 1990. Preference of the mother affects selection and avoidance of foods by lambs differing in age. Appl. Anim. Behav. Sci. 28:255–632.

Mirza S. N. and F. D. Provenza. 1994. Socially induced food avoidance in lambs: Direct or indirect maternal influence? J. Anim. Sci. 72:899‑902.

Mirzaei, M., M. Khorvash, G. R. Ghorbani, M. Kazemi-Bonchenari, A. Riasi1, A. Nabipour, and J. J. G. C. van den Borne. 2015. Effects of supplementation level and particle size of alfalfa hay on growth characteristics and rumen development in dairy calves. J. Anim. Physiol.Anim. Nutr. 99:553 -564.

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.

Munksgaard, L., M. B. Jensen, L. J. Pedersen, S. W. Hansen, and L. Matthews. 2005. Quantifying behavioral priorities – effects of time constraints on behaviour of dairy cows, *Bos taurus*. Appl. Anim. Behav. Sci. 92:3-14.

Nielsen, P. P., M. B. Jensen, and L. Lidfors. 2008. The effects of teat bar design and weaning method on behavior, intake, and gain of dairy calves. J. Dairy Sci. 91:2423-2432.

Nolte, D. L., F. D. Provenza, and D. F. Balph. 1990. The establishment and persistence of food preferences in lambs exposed to selected foods. J. Anim. Sci. 68:998–1002.

Nonnecke, B. J., M. R. Foote, J. M. Smith, B. A. Pesch, and M. E. Van Amburgh. 2003. Composition and functional capacity of blood mononuclear leukocyte populations from neonatal calves on standard and intensified milk replacer diets. J. Dairy Sci. 86:3592–604.

NRC. 2001. Nutrient Requirements of Dairy Cattle. 7th rev. ed. Natl. Acad. Sci.,Washington, DC.

O'Driscoll, K., M. A. G. von Keyserlingk, and D. M. Weary. 2006. Effects of mixing on drinking and competitive behavior of dairy calves. J. Dairy Sci. 89:229–33.

Olofsson, J. 1999. Competition for total mixed diets fed for ad libitum intake using one or four cows per feeding station. J. Dairy Sci. 82:69–79.

Panivivat, R., E. B. Kegley, J. A. Pennington, D. W. Kellogg, and S.L. Krumpelman. 2004. Growth performance and health of dairy calves bedded with different types of materials. J. Dairy Sci. 87:3736‑3745.

Phillips, C. J. C. 2004. The effects of forage provision and group size on the behavior of calves. J. Dairy Sci. 87:1380–1388.

Porter, J. C., R.G. Warner, and A.F. Kertz. 2007. Effect of fiber level and physical form of starter on growth and development of dairy calves fed no forage. Prof. Anim. Sci. 23: 395‑400.

Quigley, J. D., T. M. Steen, and S.I. Boehms. 1992. Postprandial changes of selected blood and ruminal metabolites in ruminating calves fed diets with or without hay. J. Dairy Sci. 75:228-235.

Quigley, J. D., T. A. Wolfe, and T. H. Elsasser. 2006. Effects of additional milk replacer feeding on calf health, growth, and select blood metabolites in calves. J. Dairy Sci. 89:207-216.

Reinhardt, V. and A. Reinhardt. 1981. Natural sucking performance and age of weaning in zebu cattle (Bos indicus). J. Agric. Sci. 96:309–312.

Roth, B. A., N. M. Keil, L. Gygax, and E. Hillmann. 2009. Influence of weaning method on health status and rumen development in dairy calves. J. Dairy Sci. 92:645‑656.SAS Institute. 2008.

SAS User's Guide. SAS Institute Inc., Cary, NC.

Schirmann, K., M. A. G. von Keyserlingk, D. M. Weary, D. M. Veira, and W. Heuwieser. 2009. Technical note: Validation of a system for monitoring rumination in dairy cows. J. Dairy Sci. 92: 6052-6055.

Senn, M., S. Gross-Lüem, H. Leuenberger, and W. Langhans. 2000. Meal patterns and meal-induced metabolic changes in calves fed milk ad lib. Physiol. Behav. 70:189–195.

Soberon, F., E. Raffrenato, R. W. Everett and M. E. Van Amburgh. 2012. Preweaning milk replacer intake and effects on long-term productivity of dairy calves. J. Dairy Sci. 95:783-793.

Špinka, M., R. C. Newberry, and M. Bekoff. 2001. Mammalian play: Training for the unexpected. Q. Rev. Biol. 76:141‑168.

Stanton, A.L., D.F. Kelton, S.J. Leblanc, J. Wormuth, L.K. Fox, and K.E. Leslie. 2013. Effects of tulathromycin on incidence of various diseases and growth of young heifers. J. Am.Vet. Med. Assoc. 243:267-276.

Stobo, I. J. F., J.H.B. Roy, and H. J. Gaston. 1966. Rumen development in the calf. 2. The effects of diets containing different proportions of concentrates to hay on digestive efficiency. Br. J. Nutr. 20:189-215.

Suárez, B. J., C. G. Van Reenen, N. Stockhofe, J. Dijkstra, and W. J. J. Gerrits. 2007. Effect of roughage source and roughage to concentrate ratio on animal performance and rumen development in veal calves. J. Dairy Sci. 90:2390–2403.

Suarez, B. J., C. G. Van Reenen, W. J. J. Gerrits, N. Stockhofe, A. M. van Vuuren, and J. Dijkstra. 2006. Effects of supplementing concentrates differing in carbohydrate composition in veal calf diets: II. Rumen development. J. Dairy Sci. 89:4376‑4386.

Swanson, E.W. and J. D. Harris. 1958. Development of rumination in the young calf. J. Dairy Sci. 41:1768-1776.

Sweeney, B. C., J. Rushen, D. M. Weary and A. M. de Passillé. 2010. Duration of weaning, starter intake, and weight gain of dairy calves fed large amounts of milk. J. Dairy Sci. 93:148-152.

Tamate, H., A. D. McGilliard, N. L. Jacobson, and R. Getty. 1962. Effect of various dietaries on the anatomical development of the stomach in the calf. J. Dairy Sci. 45:408–420.

Terré, M., M. Devant, and A. Bach. 2007. Effect of level of milk replacer fed to Holstein calves on performance during the preweaning period and starter digestibility at weaning. Livest. Sci. 110:82-88.

Terré, M., C. Tejero and A. Bach. 2009. Long-term effects on heifer performance of an enhanced-growth feeding programme applied during the preweaning period. J. Dairy Res. 76:331-339.

Thomas, D. B. and C. E. Hinks. 1982. The effect of changing the physical form of roughage on the performance of the early-weaned calf. Anim. Prod. 35:375‑384.

Thompson, G. B., L. D. Kintner, and W. H. Pfander. 1958. Some effects of ration preparation on alterations of the rumen mucous membrane. J. Animal Sci.17:1220.

Tomkins, T. 1991. Loose-housing experience in North America. EAAP Publication (Netherlands).

UBC AWP. 2013. UBC Animal Welfare Program: SOP - HOBO Data Loggers. pp. 1 - 23. University of British Columbia, Vancouver, Canada.

Van Putten, G. 1982. Welfare in veal calf units. Vet. Rec. 111:437–440.

Van Soest, P. J., J. B. Robertson, and B. A. Lewis. 1991. Methods for dietary fiber, neutral detergent fiber on-starch polysaccharide in relation to animal nutrition. J. Dairy Sci. 74:3583–3597.

Vasseur, E., F. Borderas, R. I. Cue, D. Lefebvre, D. Pellerin, J. Rushen, K.M. Wade, and A.M. de Passillé. 2010. A survey of dairy calf management practices in Canada that affect animal welfare. J. Dairy Sci. 93:1307–1315.

Von Keyserlingk, M. A. G., L. Brusius, and D. M. Weary. 2004. Competition for teats and feeding behavior by group-housed dairy calves. J. Dairy Sci. 87:4190–4194.

Von Keyserlingk, M. A. G., D. Olenick, and D. M. Weary. 2008. Acute behavioral effects of regrouping dairy cows. J. Dairy Sci. 91:1011-1016.

Warnick, V. D., C. W. Arave, and C. H. Mickelsen. 1977. Effects of group, individual, and isolated rearing of calves on weight gain and behavior. J. Dairy Sci. 60:947–953.

Welch J. G. and A. M. Smith. 1970. Forage quality and rumination time in cattle. J. Dairy Sci. 53:797-800.

Wise, G. H. and G. W. Anderson. 1939. Factors affecting the passage of liquids into the rumen of the dairy calf. I. Methods of administrating liquids: drinking from open pail versus sucking through a rubber nipple. J. Dairy Sci. 22:697-705.