Chapter

Incorporating Silages into Preweaned Dairy Calf Diets

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Abstract

Supplementing forage to preweaned calves has shown some positive effects, such as stabilization of the rumen environment, limiting abnormal behaviors, and increasing starter intake. However, dry forages can be limited and cost prohibitive in some areas of the world. Contrastingly, ensiled forages are commonly found on most dairy farms and are low cost. Therefore, the objective of this review was to focus specifically on ensiled forages and how they affect preweaned calves. There are few studies that have focused on providing ensiled forages and most of them have used corn silage. Although impacts on rumen development and nutrient digestibility have been variable, feed intake and efficiency were not affected in most reviewed studies. Growth and health parameters were also either not affected or improved. Therefore, with careful silage feeding management, the supplementation of ensiled feeds may be used to provide similar benefits of dry forages to preweaned dairy calves.

Keywords: rumen development, forage, digestibility, feed intake, performance

1. Introduction

Ensiled feeding has become more common around the world and is becoming an active area of calf nutrition research. So far, thorough reviews have been published on the effects of different feed type exposure to dairy calves, including the influence of forage feeding on rumen development, growth rate, feeding behavior, and many other factors in young calves [1, 2]. Also, an excellent meta-analysis on the effects of forage provision to dairy calves is available in the literature [3]. In this meta-analysis, 27 studies were evaluated and the authors found an increase in starter feed intake, average daily gain (ADG), body weight (BW) and modulation of ruminal fermentation when forage sources were offered to preweaned calves. But they also found a decrease in feed efficiency (FE) when calves were offered alfalfa hay (AH) in addition to grain based starter feed. An important conclusion from those reviews is that there are multiple interactions between the type of starter, the forage source, and the amount of forage offered, thereby, not allowing any simple guidelines to be offered to dairy farmers. Although those reviews provide excellent information on forage feeding to preweaned calves, this chapter is designed to focus specifically on ensiled forages in preweaned calf diets.

Feedstuffs for calves are separated into two categories: liquid and solid feeds. Liquid feed is either milk or milk replacer and provides the main source of nutrients for the growing calf until its gastrointestinal tract and rumen become developed enough to transition to solid feed. The solid feed is usually a grain of some kind, either whole, processed, or pelleted, with or without a forage source. The addition

of solid feed to the calf's diet should be done early in life to promote the development of the calf's rumen [1, 4]. However, the individual ingredients in solid feed for calf diets have been a hot research topic since the 1950s and earlier. As dairy production has progressed scientifically with more data and research available, farmers have struggled to keep up with current recommendations, including feeding forage sources. Therefore, calf feeding recommendations, in terms of forage supplementation, differ depending on the geographical region. Some countries, such as the United States (US), generally recommend that dairy calves are not fed forage before weaning [5]. Other countries, such as those located within the European Union (EU), recommend that these pre-ruminants are provided with a forage source, as also indicated by numerous studies on feeding forage to calves conducted in EU and their results being widely propagated in EU [6, 7], but that feeding forage can be also avoided e.g. by including whole grain in starter feed [8–10].

In a survey of eleven dairy farms in South East England, two farms supplemented hay, two supplemented silage, four supplemented straw, and three supplemented with no forage to calves [11]. The age of calves or method of forage supplementation was not described but it is concluded to be more common to provide than not to provide forage to calves in South East England. In the US, a nationwide survey indicated small farms (30–99 lactating cows) begin providing calves with forage at 31.5 days of age, medium farms (100–999 lactating cows) at 43.1 days of age, and large farms (1,000 or more) at 58.1 days of age. The forage type was not described. However, it is evident that in the US, smaller farms provide forage earlier than larger farms. In Canada, farms possessing automatic calf feeders offered hay more commonly (93% of farms) than farms using manual calf feeding (66% of farms). Age for access to hay was as early as 5–7 days and access to a total mixed ration (TMR), usually a silage based feed mix, as early as 15–30 days of age for both types of calf feeding systems [12]. An Australian farm survey reported 64% of farms allowed calves access to roughage at less than 1 week of age, 23% at 2 weeks of age, and 13% at 3 or more weeks of age. Of those farms, 62% offered hay, 23% offered straw, 13% offered hay and straw, and 2% offered grass only [13]. All of these studies support substantial differences between geographical regions in terms of feeding forages to preweaned dairy calves.

The evaluation of using ensiled feeds to enhance calf gain and health needs to be reviewed purposefully, as a separate component from dry forages. Feeding dry forages, such as hay or straw, has been reported to improve calf performance in numerous studies (as summarized, for example, by [1] or [3]); however, these dried forages, especially AH, may be difficult and expensive to obtain in certain parts of the world. Contrastingly, most farms throughout the world have some ensiled feed present on the farm that could be an easy potential feedstuff to supplement calf diets. Silages are usually staple ingredients in a lactating cow ration and, therefore, accessible and less costly than dried forages. However, based on aforementioned reports of forage feeding to calves in commercial settings [11–13] and available literature reviews [1–3], a usage of silages in diets for preweaned calves is not very common. The objective of this review is to summarize available research to determine whether ensiled forages can be considered as a valuable forage source in calf diets.

2. Why is forage important for young calves?

Although dairy calves grow and mature into functional ruminants, they are born with an underdeveloped rumen [4, 14]. These pre-ruminants need to be cared for in a way that will help develop their rumen function as well as provide them nutrients for growth and development. A smooth transition from liquid to solid feed can be accomplished by providing a good quality solid feed alongside adequate levels of

milk [1, 4]. However, the parameters for what constitutes good quality solid feed are variable, depending on the research study and the nutritionist.

Despite aforementioned discrepancies on specific recommendations for solid feed composition, it is widely accepted that concentrates, and particularly cereal grains, should be the most important ingredient of solid feed offered to dairy calves [1, 4]. This is due to the stimulatory impact of early intake of cereal grains on rumen epithelium development in calves. Compared to consumption of forages which mainly provide cellulose and hemicellulose, consumption of cereal grains which are abundant in starch, results in greater concentrations of propionate and butyrate in the rumen, in expense of acetate [15, 16]. Both propionate, and especially butyrate, are the most potent stimulators of ruminal epithelial cell proliferation [17, 18]. Thus, early intake of cereal grains by calves translates into faster ruminal papillae growth and greater surface area for nutrient absorption early in life [19, 20]. This consequently leads to higher solid feed intake, greater BW gain, and easier transition from milk or milk replacer to diets based on solid feeds only. Therefore, grain based starter feeds are a standard part of diets for preweaned dairy calves.

Because some earlier studies showed that forage intake may even decrease intake of grain based starter by calves [21, 22], it has been a common recommendation to avoid feeding forages to calves, in order to prevent the delay of rumen development [1, 4]. In some countries, such as the US, such a recommendation is widespread by extension agents and online publications articles, such as that published by the Bovine Alliance on Management and Nutrition (BAMN) which is composed of representatives from American Association of Bovine Practitioners (AABP), American Dairy Science Association (ADSA), American Feed Industry Association (AFIA), and US Department of Agriculture (USDA) [5]. However, as forage supplementation research is continued, it has become recognized that forage intake for preweaned dairy calves is also important for rumen development. In nature, ruminants evolved to efficiently use forages and thus forage intake by newborn calves is what naturally would occur.

Forage intake stimulates rumen muscle growth and the development of rumination. Calves that were offered dry forages (grass hay, Lucerne hay or straw), in addition to grain sources, were shown to have greater rumen muscle thickness and rumination earlier in life, compared to calves that were fed only concentrates [7, 23, 24]. Furthermore, faster digesta passage out of the rumen was observed and many pathological changes within ruminal epithelium were reduced. Specifically, feeding solely grain based starter feed to calves oftentimes leads to para- and hyperkeratosis, which are evident by the formation of feed and hair plaques firmly attached to the rumen mucosa and ruminal epithelium para- and hyperkeratosis [25–27]. Forage particles present in the rumen stimulate rumen motility thereby preventing plaque formation [26, 27]; whereas, abrasiveness of forage particles enhances keratinized ruminal epithelial cell desquamation thereby preventing para- and hyperkeratosis [25, 28]. Simultaneously, increased rumen motility and digesta passage out of the rumen, in combination with increased time spent ruminating, prevents excessive ruminal pH drop, via increased volatile fatty acid (VFA) passage to the omasum and increased delivery of buffers to the rumen within saliva. A very low pH is commonly reported in calves fed grain based starter feeds ad libitum and there are indications that it may have a negative impact on performance of calves [29]. Beneficial impacts of forage intake on rumen development are further supported by higher expression of some VFA transporters in ruminal epithelium of calves offered forages in addition to grain based starter feed, compared to those fed only concentrates [7], indicating that the development of ruminal epithelium may also be, to some extent, positively affected by forage intake. When forages are offered, e.g. bulky feed, this also stimulates the development of rumen capacity [7, 19], which is very limited in calves in the first several weeks of life [30].

Altogether, forage intake stabilizes the rumen environment, affects rumen capacity development, and prevents rumen epithelium abnormalities. These positive impacts of forage intake by calves were accompanied by increased solid feed intake and ADG of calves in numerous studies (for details, see latter part of the chapter) [1–3]. Likely, forage feeding to preweaned dairy calves also prepares the rumen for efficient forage digestion after weaning; however, evidence of this is limited [1].

Besides beneficial impacts on rumen development, access to forage limits abnormal behavior of calves, [6, 24, 31, 32]. These behaviors, such as sucking, licking or biting different objects, other calves or themselves, are quite often reported in dairy calves that are kept individually and fed limited amounts of liquid feeds with access to grain based starter feed only. Thus, feeding forage to calves also should be considered from a welfare viewpoint.

3. How are dry and ensiled forages different, especially with regard to preweaned dairy calves?

3.1 Cost and labor

In 2015, an invited review described changes in the dairy industry in North America, Europe, Australia, and New Zealand. One important highlight was the low average number of cows per herd, which was largest in New Zealand, at over 400, and smallest in Norway and Germany, at under 50 [33]. Although only certain nations were reported, other developed and developing countries would most likely be similar, indicating that no matter the dairy cow population in the country, most dairy farms are still small in size. This is an important distinguishing feature of the dairy industry because smaller farms have less resources, labor, and equipment.

A feeding recommendation of adding forage to calf diets can come with unforeseen problems. If a small farm were to consider this recommendation, they would have to evaluate not only what forage to provide their calves but how to process this forage, which would add required labor and equipment use.

The availability of dried forages on a dairy farm varies. Many lactating rations use either straw to add roughage to the lactating diet or high quality hay for high producing animals. Even in areas of the world where dairy farms include a significant portion of hay in their ration, current farm data from the Midwest shows a reduction in hay fed to dairy cows. One of the reasons for this is due to the lack of available hay. Many areas in the US have a severely low hay inventory due to poor growing and drying conditions making this a feedstuff that is either unavailable or too costly [34].

The cost of good quality hay at 150 Relative Feed Quality (RFQ) can be priced up to 50% more than 100 RFQ hay [35]. Due to calves and heifers not providing a current income source, farmers may be hesitant to use a higher quality, more expensive hay to meet calf forage feeding recommendations. But using lower quality forages, with higher neutral detergent fiber (NDF) and lower RFQ, for feeding young calves can be detrimental to their growth and development. Specifically, when dry forages are used in calf diets not only as a supplement aiming to ensure 'optimal' rumen development and preventing stereotypic behavior, but also as an important source of nutrients, such as protein, low quality hay can significantly reduce nutrient intake [27, 36]. The cost and availability of higher quality forages may leave farmers little choice as to what to supplement their calf diets.

There are many ways to estimate the price of ensiled feeds; however, the result is always significantly less than dried forages. In the US, corn silage (CS) can be priced around $30 per ton, resulting in less than two pennies per pound of forage. Contrastingly, AH can cost around 10 cents per pound, depending on the RFQ and

year of harvest. Additional time and labor also need to be taken into account since ensiled feeds are already chopped at the time of supplementation but dry forages need to be further chopped to provide calves with manageable (and also desirable, based on some studies; see latter parts of the chapter) particle length. Thus, feeding silages may be more justified than feeding dry forages due to lower costs, practical convenience, and higher accessibility on farms.

3.2 Moisture

The main difference between dry forages, such as hay and straw, and silages is moisture content, which is much higher for silages. The moisture of a feed can influence its palatability and acceptance for young dairy calves.

Kargar et al. [37, 38] fed reconstituted hay soaked in water to a dry matter (DM) content of 20%. When dry hay was replaced in the same concentrations in the calf starter with the moist hay, calves had similar DM intake (DMI) and ADG but digestibility of NDF was higher, and fecal scores and general appearance were also better as moisture increased. Similarly, Beiranvand et al. [39, 40] added water directly to starter diets in the summer and winter. They found that increasing moisture levels from 10 to 50% linearly increased DMI, ADG, and rumen VFA production, compared to calves eating dry calf starter in hot weather. Thus, adding a moist forage source, such as a silage, would not only provide necessary fiber to stabilize the developing rumen environment but may enhance feed intake by reducing dustiness and increasing palatability of dry, fine or pelleted calf starters.

Although soaking dry forages is difficult to apply on farm, adding water to calf starter that is already mixed with processed dry forages (e.g. chopped hay) is a possible method to enhancing starter intake. However, practical applications are also limited, especially in cold weather where water would freeze. Hot weather may also cause practical handling issues where higher moisture feeds can heat up. Although water soaked calf starter may have this problem, silage would also be difficult to handle during hot temperatures. Felton and DeVries [41] added water to a TMR for lactating cows and found an increase in feed temperature by the end of the day due to microbial respiration. This may reduce feed intake since hot silage is indicative of feed spoilage. Therefore, if silages are provided to calves, they must be changed out daily so as to prevent any palatability issues.

3.3 Forage particle length and processing

As already mentioned, the preweaned calf rumen is small and underdeveloped with a lower digestive capability and capacity. During calf growth and development, rumen weight (both full and empty) expressed as a proportion of BW increases up to the age of six months, indicating its immaturity within this period of life [30]. This immaturity especially limits intake of voluminous feeds, such as forages. This, in turn, requires solid feedstuffs provided to calves to be less bulky and more digestible as calf rumens fill quickly with less digestible feeds.

Dry forages can be fed to calves without processing or being processed prior to feeding, e.g. chopped to reduce their bulkiness to make feeding and prehension easier. Nevertheless, when calves were fed long or chopped hay, the former one was more willingly consumed, indicating that calves prefer long dry forages [42]. There are also indications that long, dry forages may be more effective in preventing stereotypic behavior of young calves [43]. However, intake of long hay was shown to vary substantially between calves and results in a lot of waste where hay is removed from hay racks but not eaten [44]. Furthermore, because intake of long hay by some animals may account for 20% of consumed DM this may reduce intake

of concentrates, efficiency of nutrient digestion, and growth of calves preweaning, as shown in several studies [31, 36, 45]. Therefore, if dry forages are fed to calves, such as hay or straw, they should be fed chopped (e.g. 2–4 cm long) and offered limited amounts in order to prevent feed waste and performance reduction due to higher intakes of feed that is not easily digested. However, chopping of dry forages requires more efforts, labor, and costs associated with feeding calves. Particularly, suitable equipment for chopping dry forages may be a limitation for some farms.

Ensiled forages are typically chopped before fermentation which reduces the bulkiness of the feedstuff. For example, CS is harvested and chopped to primarily provide adequate physically effective NDF (peNDF) to lactating dairy cows. Although variable from farm to farm and dependent on many factors, theoretical length of cut (TLC) of CS averages 3/8 – ¾ of an inch and geometric mean averages 9.5 mm [45]. The threshold particle size of particles leaving the rumen in adult cattle was reported to be under 1.18 mm geometric mean [46]. With an average geometric mean of 9.5 mm, chopped CS will increase rumen fill, however, not to the extent of long-stemmed hay; this average length should also stimulate chewing to help regulate rumen pH. Actually, there are reports indicating that providing chopped CS to calves affects rumination and feeding behavior [6, 43]. Using a chopped forage source compared with simply providing long-stemmed hay or straw will reduce rumen fill and allow the calf to eat more starter grain. Many farms also utilize an additional step prior to ensiling to further 'destroy' structure of the plant material and thus increase its digestibility in the rumen. This applies especially for whole plant CS by using processing rolls which reduce particle size and increase starch digestibility for better silage fermentation [47]. This allows the protein matrix that encapsulates the starch to be disrupted thereby improving fermentation. For a pre-ruminant with low rumen digestibility, these chopping and processing methods can allow easier utilization of nutrients. Research feeding different processed corn types within a texturized starter to calves reported the type of processed corn can influence intake, growth, and rumen parameters [48]. Various parameters were affected differently depending on whether calves received whole, roasted rolled, dry rolled or steam flaked corn within their texturized starter. Not one of these corn types was overall better than another but if ensiled feeds are processed, this may affect calf performance.

Nevertheless, the optimal particle size of forage may differ depending on inclusion of forages in the diet. Results from research using short AH at 2.92 mm compared to long at 5.04 mm (as geometric means) with low inclusion at 8% and high inclusion at 16%, on a DM basis in starter feed, showed that particle size may inhibit calf performance. If calves were fed the longer particle size, they did best with the lower inclusion level. And calves that were fed shorter particle size did best with the higher inclusion level, indicating there is a balance between length and volume of forage included in calf diets [36].

It has to be also mentioned, that forages that are finely chopped or pelleted have no beneficial impact on rumen function or performance of calves [48].

3.4 Forage type and its nutritional value

Various plant materials can be dried or ensiled, resulting in different hays and silages. The nutritive value, particularly digestibility, may differ, affecting performance of animals. For example, when grass from the same sward was dried or ensiled, NDF digestibility was higher for resulting hay than silage in bulls [49, 50]. However, studies comparing feeding the same plant material dried or ensiled to calves on nutrient digestibility and their performance are lacking. Thus, an

unequivocal answer to the question of whether dried or ensiled forage is a better source of nutrients for preweaned calves cannot be given.

Nevertheless, when it comes to dried forages, studies indicate that those having higher nutritive value (e.g. higher crude protein (CP) and lower fiber concentration), such as good quality grass or AH, are more willingly consumed by calves than those having lower nutritive value, such as straw [6]. However, good quality grass hay or AH feeding to calves was shown to reduce intake of grain based starter feed and feed efficiency, thus negatively affecting growth of calves and costs of rearing [3, 6, 43]. Therefore, feeding chopped straw to calves may be an even better option than feeding chopped grass hay or AH. Such an option may be especially attractive for farms that contend with limited resources of good quality hay. When straw is used in diets for calves, the aim of its feeding is simply to include forage in the diet in order to ensure proper physical stimulation for the rumen, rumination, and to limit stereotypic behavior of animals.

On the other hand, not many studies compare impact of various ensiled forages on feed intake and performance of calves. Of those available, triticale silage was more willingly consumed by calves than CS, and also its feeding resulted in higher starter feed intake; however, ADG of calves and FE was not affected [6]. Nevertheless, in the majority of studies, CS feeding to calves was investigated (see **Table 1**) due to common usage of this feed in dairy production. Compared to other forages, CS has also substantial starch content. Thus, this feed can be considered as not only a source of fiber and physical structure in the diet, but also a source of easily fermentable starch in the rumen. Whole crop silages may, therefore, be an especially attractive source of forage for preweaned calves.

3.5 Microbials

The principle of silage fermentation is to convert water-soluble carbohydrates into organic acids. In an anaerobic environment, lactic acid bacteria are able to rapidly reduce the pH and increase stability of the silage. The resulting fermented product contains populations of lactobacilli and other microbial species [56] that, in general, are lacking in dry forages.

There have been hundreds of published papers evaluating probiotics and their effects on health and productive parameters of dairy calves. From meta-analyses, many reviews present nonsignificant or positive responses in growth, feed efficiency, and health when microbial-based products have been fed to growing calves [57]. Conclusions tend to support the use of probiotics as low risk with a potential positive benefit for the growing calf.

Many of these probiotics include lactobacilli species which are also found in properly fermented silages. Hypothetically, the question would be whether supplementing calves with silage could potentially enhance their rumen and intestinal microbiota similar to probiotic supplements available on the market. Xu et al. [58] evaluated the use of *Saccharomyces cerevisiae*, which is reported to promote rumen development, as a silage inoculant. In the fermented silage end product, they found higher microbial communities of *S. cerevisiae*, which further increased in abundance after aerobic exposure. Furthermore, one study reported positive effects feeding *Lactobacillus plantarum*, a commonly used silage inoculant, to preweaned dairy calves. The treatments of *L. plantarum* were fed to calves at 0, 4, and 8 g/day resulting in positive linear growth and fecal score improvements [59]. Other research is being conducted to determine whether some of these silage inoculant bacteria types may help enhance the health and performance of animals when directly fed. This could also be an added benefit for supplementing growing dairy calves with ensiled feeds.

Forage source[1]	Calves/ trmt	Start (d)	Weaning (d)	Forage (%)	Feeding method[2]	Starter form	ADG	DMI	FE[3]	Rumen[4]	Reference
Sta + AH, Sta + CS, Sta + AH + CS	10	3	50	10, 10, 5	TMR	Fine ground	NS	NS	ND	ND	Kargar et al. [37]
Sta + CS, Sta + RAH Sta + RBP	18	3	50	10	TMR	Ground	NS[5]	NS	NS	NS	Kargar et al. [38]
Sta, Sta + CS, CS	15	3	49	0, 50, 100	TMR	Texturized	NS	NS	NS	- CS	Kehoe et al. [51]
Sta, Sta + AH, Sta + CS	10	3	49	0, 15, 15	TMR	Fine ground	+ CS	+ CS	ND[6]	+ CS	Mirzaei et al. [32]
Sta, Sta + CS	12	3	56	0, 15	TMR	Ground, pelleted	+ CS	NS	NS	+pH, +acetate	Mirzaei et al. [52]
Sta, Sta + GH TMR, Sta + GH sep, TMR	6	1	50	0, 15, Ad lib, 71	Variable	Texturized	NS	- TMR	NS	NS	Overvest et al. [53]
Sta, TS, CS	20	14.1 +/− 4.2	57	Ad libitum	Free choice	Pelleted	+ TS, CS	+ TS	NS	ND	Castells et al. [6]
Sta, Sta + CS	8	10	70	0, 30, 60	TMR	Pelleted	NS	NS	NS	- CS	Suarez et al. [54]
Sta + CS	10	8	35	0, 33.7	TMR	Ground	NS	NS	ND	+ CS	Block and Shellenberger [55]

[1]Sta: Calf starter treatment without forage inclusion, RAH: Reconstituted alfalfa hay; RBP: reconstituted beet pulp, AH: Alfalfa hay, CS: corn silage, GH: grass hay, Sta + GH sep: Starter and grass hay fed separately.
[2]TMR: Total mixed ration based on 37% CS and 34% legume haylage, TS: Triticale silage.
[3]FE: Gain to feed ratio.
[4]Rumen: Rumen development parameters evaluated by BHB concentrations, pH, VFAs or physical appearance including papillae parameters.
[5]NS: Not significant ($P \geq 0.05$).
[6]ND: Not determined.

Table 1.
A summary of studies evaluating corn silage in pre-weaned dairy calf diets.

3.6 Palatability

Palatability is defined as the collective aspects of a feed material that are sensed before being swallowed. Adult cows have been reported to enjoy sweet and umami flavors and avoid bitter tastes although not to the extent as other mammals, such as sheep [60]. There are few research studies that report on palatability in calves. Calf palatability and preference have been researched mostly in regard to ingredient use in calf starters. Calves have clear preferences for certain ingredients that should be considered when formulating their feedstuffs. Wheat meal and soybean meal were most preferred; however, previous experience with these ingredients, difference in age, and current nutrition status (whether receiving enough milk and nutrients) can play an influential role [61]. On the other hand, no typical preference tests for forages were conducted in calves. However, based on results of Castells et al. [6] it can be concluded that AH and oat hay is more willingly consumed by preweaned calves, and thus likely more palatable, than ryegrass hay, barley straw, CS, and triticale silage.

As opposed to dry forages, silages are acidic and this acidic taste may potentially affect their intake. Similar to what is known for adult cattle, calves have a preference for sweet flavors such as found in whole milk [62]. However, they will consume feedstuffs with a lower pH, such as acidified milk and milk replacer, which have been fed for decades to preweaned dairy calves. In the US, 1.7% of farms feed acidified milk by using an organic acid to preserve the milk so it can be stored and fed at ambient temperatures [63]. Typical pH range of acidified milk or milk replacer can be anywhere from 5.5 to as low as 4.0; if pH drops too low, research has found decreased intake as reported with acidification with citric acid between a pH of 4.2 and 5.2 [64]. Since silages can be acidified anywhere from 3.8–5.5 depending on their forage source [56], it can be speculated that this may have some inhibitory effect on palatability and DMI. Nevertheless, studies conducted so far indicate that at least palatability of CS or triticale silage for calves is more or less comparable to palatability of different dry forages [6, 32].

It is also worth mentioning that the preference for certain tastes can result from the nutrients contained in the feedstuff. For example, sweet flavor may be preferred due the correlation with the presence of carbohydrates and umami may be preferred due to the presence of amino acids within the feedstuff. In adult animals, post-ingestive feedback plays a large role in preference for feed types [65]; however, preweaned calves have a low solid feed intake and may not be influenced by this.

4. What are the effects of feeding silage on performance parameters in dairy calves?

Taking into account information presented in previous paragraphs, silages possess potential advantages and disadvantages when it comes to feeding them to preweaned calves. Hence, the following paragraphs will focus on the effects of feeding ensiled feedstuffs on rumen development and digestibility, feed intake, and growth and health parameters in preweaned dairy calves and will discuss those in terms of practical application of silages in calf diets.

4.1 Rumen development and digestibility

The impact of forage quality and quantity has been well established in lactating cows and has also been shown in previous reviews to affect preweaned calves [2, 3]. In this review, which focuses solely on silages, there seems to be a similar impact on

rumen development and rumen functions of feeding silage in addition to calf starter as dry forages, compared to feeding calf starter only.

When CS was provided to calves in addition to calf starter, rumen pH significantly increased compared to only calf starter feeding [32, 52]. This ensiled forage source acts similarly to its inclusion in lactating rations, stimulating chewing to increase saliva and buffer the VFAs and resulting acids in the rumen. Calves that are fed a readily fermentable feed, such as a ground or fine calf starter can develop low rumen pH which can lead to keratinization and ulceration of the rumen wall and feed plaque formation [25, 27, 66]. At day 35, calves fed CS mixed with ground or texturized starter had higher ruminal pH (5.98 vs. 5.31) compared to calves that did not receive CS in their starter [52]. Calves that were fed AH, CS or a mixture of both, tended to increase their meal length and decrease their eating rate when fed CS compared with AH but significantly increased their rumination length [67]. This indicates that although CS did not take as long to eat as AH, calves spent time ruminating which would lead to increased salivation and improved rumen environment via delivery of more buffering substances into the rumen.

High fiber and high DMI diets tend to decrease digestibility in weaned calves [68, 69] so it is important to evaluate whether the addition of a forage source would reduce feedstuff digestibility in the preweaned calf. Adding forage to preweaned calf diets increases the fiber content of the diet which may lead to a decrease in digestibility and nutrient intake. Calves that were supplemented with triticale silage had greater CP intake compared to control calves fed only calf starter (235 vs. 171 g/d) but due to the higher fiber and bulkiness of the triticale silage, CP content of the total diet consumed relative to the control calves was actually decreased by 0.4 percentage units. However, an increase was seen in CP digestibility when calves were offered (in addition to starter feed) AH, rye hay, and CS compared to control, oat hay and barley straw with triticale silage being intermediate [6]. The digestibility of NDF in CS treatment was also significantly higher than AH soaked in water [38] which may be attributed to the fermentation the corn plant undergoes in the silo [70]. This is a positive effect since the microbes have begun the process of breaking down the nutrients thereby making it easier for the pre-ruminant calf to access them in their underdeveloped rumen environment. Although the bulkiness of silages can reduce the total intake of nutrients, because the digestibility of these nutrients increases, there is no negative impact on calf performance, especially when silage is fed in addition to starter feed, since the overall amount fed is rather small [6].

The evaluation of rumen parameters from the previous section, and also from other research trials, include physical rumen appearance of color and feed plaque formation, rumen papillae morphology, rumen papillae density, and rumen wall thickness. In studies conducted in 1980, calves fed CS had significantly shorter papillae (0.9, 3.5, 1.6 cm^3 for CS, pellets, and wood fines, respectively) but those were more dense (118.1, 51.9, 66.4 No./cm^2 for CS, pellets, and wood fines, respectively) compared to calves fed pellets or pellets with wood fines [55]. In a different study, 100% of calves fed solely calf starter had rumen plaque compared with 63% of calves fed a mixture of 40:60 starter and CS and 88% of calves fed 70:30 starter and CS. Additionally, 25% of calves fed 40:60 mixture had poor development of mucosa [54]. Rumen weight was highest and ventral muscle thickness was lowest for calves fed calf starter only compared to treatments receiving CS. The authors hypothesized that this may be influenced by feed plaque formation. Although the plaque formation was concerning, the authors concluded that microscopic evaluation of the rumen was not significantly different among treatments and that, overall, calves were healthy and silage can be added to the diet [54].

In a study in which calves were fed solely with CS without calf starter, reduced papillae length and width was observed, compared with calves fed CS and starter

(50:50 DM) and calves fed only calf starter. Papillae concentration was not different from the CS and starter mixture with CS but denser than calf starter alone [51]. Only this study evaluated intestinal morphology where CS treatment had the shortest crypt depth and mucosa thickness (villus length plus crypt depth). The authors hypothesized that lower dietary protein intake in CS only calves could have been one of the factors leading to these results; a lack of calf starter in the diet would not only reduce VFA production but dietary protein intake since CS is low in CP. This morphology indicates a potential reduction of surface area for nutrient absorption in the rumen as well as epithelial cell proliferation in the intestine.

Butyrate concentration in the rumen has long been a standard indicator of the potential of a feed to stimulate rumen development in the calf because it is the main stimulatory VFA for rumen epithelial development [71]. It should follow that the metabolized form of butyrate, ß-hydroxybutyrate (BHB), should be increased in the blood if feed consumed promotes ruminal butyrate production, and thus enhances rumen development. In fact, the supplementation of sodium butyrate in the feed has been reported to improve rumen and gastrointestinal development in preweaned calves [72]. Although not all silage research trials reported on rumen development, of the ones that did, only a few showed increases in blood BHB or other rumen parameters when calves were fed silages. For example, calves fed CS were reported to have lower blood BHB concentrations [37], not different [51, 53] or higher BHB blood concentrations [32], compared to calves fed diets without silages. Therefore, blood BHB concentration may not be the best indicator of rumen development and potential of a feed to stimulate rumen development since it may be strongly influenced by differences in trial methods, such as starter quality, forage type, and forage quality or quantity.

The type of starter fed has an influence on how forage inclusion affects rumen parameters. When calves were fed a pelleted versus texturized starter with or without forage inclusion, calves receiving the pelleted starter with forage had a higher rumen fluid pH and intake than calves on just the pelleted starter. Similarly, calves receiving texturized starter had similar rumen pH to calves fed the pelleted starter with forage [9]. This indicates that forage is especially appropriate to include in the diet when the type of starter provided leads to apparent reduction in rumen pH. Adding a dry forage source to a pelleted starter has also been shown to increase post-weaning DMI and live weight [24, 73]. The only available study suggests that when ensiled feed (CS) is combined with a different form of starter feed, no impact on rumen pH can be expected; however, in that study, starter feed form (mesh or texturized) also had no impact on rumen pH [52]. Dry forage has different qualities from ensiled forage so more research needs to be done to discover whether a similar impact on rumen pH can be expected depending on the physical form of starter feed offered to calves. Also, different types of starter quality makes it difficult to compare results from research projects attempting to evaluate forage effectiveness in calf diets. However, the cost of pelleted or ground calf starter is lower than a texturized starter, making it more attractive to farms looking to reduce cost; forage supplementation may positively affect feeding such starter feeds or even may be required.

In summary, supplementing preweaned calves with ensiled feeds results in variable rumen development and nutrient digestibility. About half of the trials reported benefits and the other half reported reductions in either pH, VFAs or morphometric analyses.

4.2 Feed intake parameters

In older dairy cattle, particle length and moisture content can affect DMI but, as seen in **Table 1**, the majority of research trials evaluating feeding silages to calves compared to feeding dry forages or only calf starter reported no differences in DMI.

Only Castells et al. [6] did find lower intake of silages compared to some (but not all) dry forages tested in their study. However, in their study, calves were offered silages separately from starter feed, allowing them to choose to consume it rather than being 'force-fed' in a TMR protocol such as in other trials. This caused forage intake to decrease but inversely increased calf starter intake [6]. Although triticale silage and CS were consumed at only half the amount of AH and oat hays, similarly to rye hay and barley straw, the calves having access to silages increased starter consumption to a higher level than calves fed AH. In fact, triticale silage significantly increased total DMI and ADG compared to calves fed only starter and AH. This could be due to rumen fill [1]; however, considering intake of the triticale silage was only half of AH, this is not likely. Calves offered CS had greater ADG than calves fed only starter, although in the end, there were no differences between any treatments for gain to feed ratios. Thus, method of feeding ensiled forages may be an important factor affecting final results of their use in diets for calves. Perhaps the silage pH may inhibit its willing consumption, as discussed previously, or simply silages fed separately are more difficult to eat. Nevertheless, feeding ensiled forages as a mixture with grain based starter feed seems the best option to ensure ensiled forages are willingly consumed.

Mirzaei et al. [32] reported a significant increase of DMI when starter feed was mixed with CS compared to AH. The increase in dietary moisture level may have increased digestibility [37, 38], and thus feed intake, or palatability, by reducing dustiness of the TMR. Supportive of the latter, when calves were fed CS compared to reconstituted AH, where AH was soaked in water to reach a moisture of 20% DM to match the DM% of CS provided, no differences were reported in overall feed intake [37, 38]. This indicates that moisture may play a role in palatability and DMI of calves. Contrary to this, calves fed a TMR based on CS and legume haylage had significantly reduced DMI, although as-fed feed intake was not different from calves fed only starter, or starter supplemented with chopped grass hay in TMR or chopped grass hay separately. The TMR had significantly lower DM% at 51% compared with the other treatments which all were 88–90% concluding that calves were unable to eat enough DM to make up for the higher moisture [53].

Thus, keeping in mind calf palatability and digestive capacity, the amount of forage provided should be restricted if mixed in a TMR fashion. When calves were allowed to choose how much forage they ate with their calf starter, silages were consumed at 4 and 5% for triticale and corn silage, respectively [6]. Dried forages were not much higher at 8, 5, and 4% for oat hay, barley straw, and rye hay, respectively. Other research trials have fed a TMR style where percentages were anywhere from 30 to 60% of DM [51, 54] and some positive effects, such as increasing DMI, ADG or FE were not seen. It has been shown that mixing forages at higher levels (up to 10% DM) can reduce ADG and DMI [21, 22]. Based on result of studies in which ensiled forages were fed as a mixture with starter feed it seems that their inclusion of up to 15% of DM does not negatively affect DMI [32, 52].

Some of the lack of differences in DMI may relate to the type of calf starter fed with the forage, as already discussed for potential interaction between forage type and starter feed form. Corn silage mixed with a pelleted starter containing either barley grain or corn grain increased overall and post-weaning feed intake as compared to AH fed with either grain [32]. Others also found an increase in DMI with a pelleted starter [6]. On the other hand, different researchers that fed a texturized starter saw no differences in performance parameters for calves fed with or without CS [51, 52], although feed intake was increased in some of those when CS was mixed with texturized starter [52]. Another research study using a pelleted starter found an increase in CS DMI compared with a diet with added straw but no differences compared to the control treatment fed only calf starter [54]. More studies in dairy calves are needed on the form of starter feed and particle size of ensiled feeds and their effects on DMI.

In summary, feeding ensiled forages to calves has little effect on DMI and FE. The moisture difference of silage compared to dry forages or only calf starter may increase palatability of feed for preweaned dairy calves. However, more research is needed on the interaction of starter feed form and particle size of ensiled feeds. Keeping silage inclusion below 15% of DM is important to allow for calves to intake their solid feed to their full potential.

4.3 Growth and health parameters

The increase of DMI will usually increase BW and ADG due to an increase in nutrient intake. Because in the majority of studies in which ensiled forages were fed to calves, overall DMI was increased (**Table 1**), BW and ADG of animals were also positively affected. For example, regardless of calf starter form (mash vs. textured), calves receiving CS had significantly greater preweaning ADG (564 vs. 411 g/d) and overall ADG (598 vs. 443 g/d; 61) compared to calves not receiving CS in their diet.

An obvious explanation for this is already discussed and reported in numerous studies explaining the positive impact of feeding forages on rumen environment, nutrient digestibility, or both. Another explanation, already partially discussed, could be that ensiled feeds, especially CS, contain higher levels of digestible starch which is a valuable nutrient addition to the rumen environment. Since most trials discussed in this paper utilize CS as the main ensiled feed, it is important to keep in mind that other ensiled feeds may have different results. Starch content and digestibility in CS is much higher than in hays such as AH and, especially, straw. The starch content of CS is typically 25 to 35% and starch digestibility of CS that has been kernel processed can be over 87%. In comparison to AH and straw, which contain mostly structural carbohydrates and little starch [74], CS starch content can improve the rumen environment. And lastly, a third explanation could be that calves receiving forage ruminated more and had reduced nonnutritive behaviors, which would lead to greater DMI and, therefore, ADG [6, 32]. Interestingly, these two research trials found opposite effects where Mirzaei et al. [32] reported calves supplemented with CS spent more time ruminating compared with AH but Castells et al. [6] reported calves fed AH spent more time ruminating compared to other groups, including the CS group. The difference may be with the feeding method where the former trial fed a TMR and the latter trial fed starter and forage separately. However, both trials found that non-forage supplemented treatments had the lowest rumination times and highest non-nutritive oral behaviors as well as lower feed intake and ADG.

Other studies evaluating ensiled forage compared with a dry hay or only calf starter reported no differences in BW or nutrient intake. Research using veal calves concluded that forage may be added to the veal calf diet since performance parameters were not affected. No difference in BW at slaughter was reported with ADG ranging from 688 to 779 g/d [54]. Even in research where DMI was reduced in calves fed TMR (a silage based lactating ration TMR) with a low DM (51.5% DM), due to higher milk intakes, calves were able to maintain their ADG until weaning [53]. Once at weaning and during post-weaning, TMR fed calves reduced ADG due to the higher moisture content and diluted nutrient content compared with calves receiving starter, starter mixed with grass hay, and starter fed separately from grass hay.

Health scores of calves, if reported, were also not different for most trials [38, 51, 52]. One research trial reported a tendency of higher rectal temperature probability (≥40°C) before weaning in CS fed calves compared to calves fed reconstituted beet pulp, which was soaked in water to 20% DM ($P \leq 0.08$) and a lower probability of having pneumonia ($P \leq 0.09$). Since number of days and treatment frequency were not different, it was concluded that calves were in general very

healthy and these data were unusual [38]. Overall, the addition of ensiled forages to calf diets has no effect on health parameters.

In summary, although there were some negative rumen parameter and digestibility effects, ensiled feeds either had no effect or a positive effect on other performance parameters, such as ADG and health. If a farmer were to incorporate ensiled feeds into their calf nutrition plan, they would most likely see positive or no effects on calf growth, health and feed intake.

5. Potential limitations of feeding ensiled forages to calves

As with any new practical application, the addition of ensiled forages to calf diets needs to be evaluated carefully on each farm. There are limitations that come with the addition of ensiled forages to calf diets. But with careful management, these can be overcome and this type of feedstuff can become useful and advantageous for use on farm.

As mentioned in a previous section, ensiled feed will heat up during the day when exposed to oxygen. This indicates bacterial respiration which can not only reduce nutrients and DM but palatability [75]. Because silages are made throughout the world, there are challenges to overcome when ensiling forages, especially in hot or cold climates [76]. Although most of the studies reviewed in this chapter have not found reductions in silage consumption if fed in low amounts in TMR style, feeding well fermented silage needs to be a priority; young animals are typically most susceptible to poor nutrition.

With increasing knowledge of proper ensiling practices, it is well known that mycotoxins may be produced when silage is not properly fermented [77]. Mycotoxins are secondary metabolites of fungi that may be produced due to a number of different factors, such as weather, improper packing and sealing, and forage quality and moisture. They can cause adverse health effects and have been reported in young growing animals, such as juvenile goats, to reduce growth and immune system function [78]. When considering the addition of ensiled feeds to calf diets, the quality of the ensiled feed needs to be evaluated. Spoiled or hot silage should not be fed to young animals.

Although this chapter refers to silages in general, most research has been done with CS. Only one of the research papers presented used triticale silage with all others using CS [6]. The nutritional properties of CS compared to other silages being used worldwide, such as oatlage, barlage, or sugar cane silage, can be very different in nutritional content. It is important to keep this in mind when considering the implementation of feeding ensiled forage to calves.

All of these limitations can be overcome with careful management and planning. To overcome these limitations, farmers should consider their calf feeding management. If the farm is able to change out solid feed on a daily basis, the old, heated silage will be replaced with more palatable feed. If the farm is currently using proper silage management techniques during harvesting, storage, and feedout, this will reduce the chances of mycotoxins being fed to young calves. And if the farm feeds a different silage than CS, they should consider its slow incorporation and evaluating its effects on their calves since more research needs to be done using different ensiled forages in calf diets.

6. Conclusions

Corn silage (CS), haylage, and other small grain and grass silages are fermented to improve digestibility and nutrient access which can be beneficial to animals

whose rumen is not fully developed. Silages also contain other byproducts such as active microbes that may be beneficial in a probiotic sense. With the reduced accessibility of good quality hay in certain parts of the world, silages may be the answer as a common feedstuff found on farm that is low in cost for the farmer. Without the need of further processing, silages can be easily utilized in a preweaned calf diet.

As dairy markets continue to be volatile and farmers are faced with tough economic choices, the search continues for providing good quality feed at a lower cost. Research shows that the addition of silage to calf feed either does not affect or may have a positive influence on calf growth and performance. Although some trials reported some reduction in rumen parameters, at the same time these trials showed no differences in calf growth and health compared to no forage or other forage treatments. Keeping in mind some limitations of ensiled forages, this review indicates that silages may be used for preweaned calf diets. Silage management is important since this fermented feed may heat during the day; using small amounts mixed into calf starter like a TMR and providing fresh silage daily can allow ensiled feeds to be easily incorporated into calf diets on farm. Further research is required with different types of silages and mixtures and each farmer should assess this available feedstuff carefully on their own farm.

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