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Feeding management for early rumen development in calves

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Abstract
Young calves are physically as well as functionally represents two different types of animals about their digestive system. Development of the rumen after birth represents very important physiological challenge for young calves. Therefore, calf feeding is critical to provide the nutrients needed to achieve the calf's full potential for growth. The production of VFAs is essential to the development of the rumen papillae. Feeding of forage resulted in production of acetic acid rather than butyric acid. Feeding of grains and butyrate are the key elements enhancing the papillae growth and overall rumen development. During this period, water plays critical role, to create the correct rumen environment that will support fermentation and production of VFAs, which will in turn stimulate rumen development. Feeding of purified slats of butyrate also enhances the rumen development.

Keywords: Rumen, fatty acids, calf

1. Introduction
The calf is functionally a monogastric. At birth all four compartment of ruminant stomach except abomasum are nonfunctional, undeveloped, and small in size and disproportionate to the adult digestive system [1]. The rumen of the neonatal calf occupies about 25% volume of the whole stomach [2]. The rumen only starts to grow at two to three weeks of age and growth will continue until about 6 months of age. In these first weeks of life, the milk bypasses the rumen, reticulum and omasum. During this period non-functional and undeveloped rumen, reticulum and omasum do not play any role in digestion.

The cost of raising a calf can be decreased by judicious management of feeding to achieve the early rumen development. Young calves are unique at birth they are physically and functionally two different types of animals with respect to their gastro-intestinal system. At birth the physical attributes distinguishing a ruminant from a mono-gastric animal i.e, the reticulum, rumen, and omasum are present. On the other hand, rudimentary reticulo-rumen and omasum, esophageal groove, developing abomasal and intestinal enzymes stimulates neonatal ruminants to function as mono-gastric animals [3] subsisting on milk-based diets, which are digested and assimilated quite efficiently [4].

Fast rumen development in young calves facilitates important changes in metabolites that may have synergistic effects on growth [5]. Development of the rumen is an important physiological challenge for young ruminants [6]. Inoculation and establishment of the anaerobic microbial ecosystem, initiation of solid feed intake, the accompanying fermentation processes and absorption mechanisms are all needed to trigger the development of the rumen [7]. Various strategies have been used to speed up the process including: increased scratch factor, added VFA's, supplemental bacteria, altered feeding schedules, additional nutrient sources and particle size changes [8, 9].

Digestive enzymatic changes coupled with the high daily costs of maintaining a preweaned calf result in an ability and need to transition the calf from a monogastric animal to a ruminant. A smooth transition from a monogastric to ruminant animal, with minimum loss in growth, requires the development of the reticulo-rumen and its associated microbial population for efficient utilization of dry and forage-based diets [10]. The rumen development appears to be greatly affected by diet and dietary changes [11]. Calves fed exclusively on milk/milk replacer show least metabolic activity of rumen epithelium. If the rumen is well developed and will be able to produce VFA from roughage and concentrate, the energy can be used for the development of other organs and systems in the calf.

A rumen is well developed if the amount of papillae and the size of the papillae are greatly increased, so the total absorption surface is extended and more nutrients can be absorbed.
The factors responsible for initiating cellular growth and maturation of the non-functional rumen tissues and establishing rumen development and function in the neonatal calf are having greatest importance.

2. Development of rumen

2.1 Microbial Colonization of the Rumen

Microbial colonization of the rumen of the newborn animal represents a key-step in the development of rumen functionality [12]. The mature rumen harbours a complex microbial population, with bacteria being dominant followed by protozoa and fungi, but newborn calves have sterile rumen. The rapid establishment of an active rumen microbial population before weaning, leading to a faster development of rumen function, would be very beneficial for the animal health and productivity. However, within 1 to 2 days after birth, the rumen starts to be colonized with numerous microbes [13]. The rumen microbiota is necessary for the proper physiological development of the rumen and for the animal's ability to digest and convert plant mass into food products. The microbiota was responsive to dietary modifications as well as physiological changes in the host [14].
Microbial colonization of the neonatal rumen initiates a cascade of growth and developmental changes in the host animal that ultimately allow the animal to function as a true ruminant. A broad class of rumen microbes (e.g., amylolytic, cellulolytic, proteolytic, and lactate-utilizing) change with age and diet in young dairy calves. The earlier dry feed is introduced into the calf's rumen, the earlier microbial development occurs, resulting in higher ruminal metabolic activity and increased total VFA concentrations of rumen contents [14].
The growth promoting agents for ruminal papillae are not the ruminal microbiota alone or dry feed alone. Rather, it is the fermentation end product butyrate responsible for the growth of ruminal papillae [15]. This is substantiated by direct administration of butyrate either into the oral cavity or into the rumens of cannulated animals [16] or also by inclusion of butyrate in calf feed [17].

2.2 Morphological Development of the Rumen

The rumen is composed of stratified epithelium with an outer keratin layer. Morphologically, from the lumen surface, 4 distinct layers can be visualized: stratum corneum, stratum granulosum, stratum spinosum, and stratum basale. Ruminal papillae are present at birth on the luminal surface of the entire rumen; they can be visualized macroscopically. Morphological development of the rumen mainly refers to papillae characteristics, muscle thickness, and organ size [18]. Papillae length, width, and area increase with age and are responsible for absorption to diet and butyrate. Rumen morphology can also be studied at the microscopic level. Feeding animal highly fermentable diets or pelleted diets [19] or the infusion of butyrate can cause morphological modification in ruminal papillae.

2.3 Rudimentary Reticulo-Rumen

The reticulo-rumen of dairy calf's most rapid growth prior to 8 week of age and the relative mature size probably is attained by 12 weeks. The reticulo-rumen of animals will be smaller than normal for their age, with thinner walls, lower capacity, and will lack normal development and coloration of papillae [20]. The rumen wall is thin and slightly transparent and reticulo-rumen volume is minimam [21]. The ingestion of roughages is stimulated the development of reticulo-rumen in terms of weight and thickness of the tissues and the development of normal papillae [22]. Ruminant animals require a physically and functionally developed rumen to meet the demands of an innate desire to consume forages and dry feeds. However, the neonatal rumen will remain undeveloped if diet requirements for rumen development are not provided.

2.4 Changes in Rumen Epithelium

Proliferation and growth of squamous epithelial cells causes increase in length and width of papillae, and thickness of the interior rumen wall [23]. The presence and absorption of volatile fatty acids stimulates rumen epithelial metabolism and may be key in initiating rumen epithelial development [24]. During the transition from a pre-ruminant to a ruminant animal, growth and development of the ruminal absorptive surface area (papillae) is essential to enable absorption and utilization of digestion end products, specifically rumen volatile fatty acids [21]. The ingestion of dry feeds produce microbial end products sufficiently stimulates rumen epithelial development [25, 26]. However, the stimulatory effects of different volatile fatty acids are not equal, butyrate being most stimulatory, followed by propionate. Low activity of the acetyl- CoA synthetase enzyme appears to limit rumen epithelial metabolism of acetate, thereby limiting acetate's ability to stimulate epithelial development. Butyrate metabolism by the epithelium appears to increase concomitantly with decreasing rumen pH and increasing butyrate concentrations [24]. A continuous presence of volatile fatty acids maintains rumen papillae growth, size, and function. Therefore, it is likely that diets composed of milk, concentrates, or forages affect the rate and extent of rumen epithelial growth differently.

3. Requirements for rumen development

3.1 Establishment of Bacteria

When the calf is born, rumen is completely sterile. Young ruminants probably acquire rumen bacteria mainly through feed and interanimal contact [27]. The sequence of establishment of the rumen bacterial population appears to be primarily dependent on the diet of the calf [13]. Bacterial inoculation occurs almost immediately through contact with other animals and the environment. However, by one day of age, a large concentration of bacteria can be found mostly aerobic (or oxygen-using) bacteria. It would indeed be possible to promote different microbial populations establishing in the rumen of the young animal by manipulating the feeding management early in life that persisted in later life [28]. Afterwards, total number of bacteria/ ml of rumen fluid do not change drastically, but type of bacteria changes as the calf begins to consume dry feed. Acetic and propionic acids are absorbed through the rumen wall and are converted into metabolites that the calf uses as energy sources. Butyric acid is not absorbed through the rumen wall and is instead converted into an energy source used by cells in the rumen wall for efficient rumen development.
As dry feed intake increases, number and type of bacteria change from aerobes to anaerobes and facultative anaerobes [4]. This results in a loss of aerobic microbes and causes development of anaerobic microbes with increase in intake of dry feed. Many methanogens (methane producers), proteolytic

(protein degraders), and cellulolytic (cellulose degraders) become established.

3.2 Liquid in the Rumen

Rumen bacteria must live in a water environment. Without sufficient water, bacteria cannot grow and ruminal development is slowed. Water in the rumen liquor comes mostly from free water intake. If water is offered to calves from an early age, this is not usually a problem unfortunately, many producers do not provide free water to their calves until calves reach 4 weeks of age may delay starter intake by several weeks [29]. Feeding of water can increase body weight gain, starter intake, and reduce scours. Diets high in salt, sodium bicarbonate, or protein appear to stimulate water intake [30]. High-forage diets might also increase water requirements by increasing the loss of water in feces and urine [31].

3.3 Outflow of Material from the Rumen (muscular action)

Rumen muscularity can be stimulated by inert materials but they don't stimulate epithelial development [1]. No regurgitation occurs in the first week of life. Measures of ruminal activity include rumen contractions, rumen pressure, and regurgitation (cud chewing). With the increase in intake of dry feed, ruminal contraction begins. When calves are fed milk, hay, and grain shortly after birth, normal rumen contractions can be measured as early as 3 weeks of age [32]. However, when calves are fed only milk, normal rumen contractions may not be measure for extended periods.

3.4 Absorptive Ability of the Rumen Tissue

The absorption of end-products of fermentation is an important criterion of ruminal development. The fermentation end-products, especially volatile fatty acids (acetate, propionate, and butyrate) are absorbed into the rumen epithelium, where propionate and butyrate are metabolized in mature ruminants [1]. However, there is little or no absorption or metabolism of VFA in neonatal calves. Therefore, the rumen must develop this ability prior to weaning.

The rumen wall consists of two layers - the epithelial and muscular layers. Each layer of rumen has its own specific functions and develops according to the different stimuli. The epithelial layer is the absorptive layer of tissue that is inside the rumen and is in contact with the rumen contents. It is composed of a very thin film of tissue holding many small finger-like projections called papillae. These papillae provide the absorptive surface for the rumen. At birth, the papillae are small and non-functional. The primary stimulus for development of the epithelium is VFA– particularly propionate and butyrate. Therefore, rumen development is primarily controlled by chemical, not physical means. Ruminal development is primarily driven by the availability of dry feed, but particularly starter, in the rumen. The muscle layer lies on the exterior of the rumen and provides support for the interior (epithelial layer). Its primary role is to contract to move the ruminal contents around in the rumen and move digesta into the omasum.

3.5 Availability of Substrate

The primary factor determining ruminal development is dry feed intake. To promote early rumen development and allow early weaning, the key factor is early consumption of a diet to promote growth of the ruminal epithelium and ruminal motility. Because grains provide fermentable carbohydrates that are fermented to propionate and butyrate, they ensure early rumen development. On the other hand, the structural carbohydrate of forage tends to be fermented to a greater extent to acetate, which is less stimulatory to ruminal development. Early and aggressive intake of calf starter is the key to good rumen development.

4. Effects of different dietary ingredients on rumen development

4.1 Liquids feed and Rumen development

Milk or milk replacer is primary diet of neonatal calves. The chemical composition of liquid feed (milk) and the shunting effect of the esophageal groove limit its ability to stimulate rumen development [21]. When calves drink milk, either from a teat, bottle, or bucket, reflexive closure of the esophageal groove occurs. The milk will enter the abomasum by way of the reticular and omasal grooves [33]. This shunts milk pass the reticulo-rumen into the abomasum and keeps the consumed milk from being fermented in the rumen. The metabolic activity in the rumen epithelium of young calves fed exclusively on milk/milk replacer is limited and minimal absorption of volatile fatty acids occurs. Though with age the calf may have an increase in rumen size, the rumen function will still be underdeveloped when only milk or milk replacer are fed. Therefore, although milk based diet promote rapid and efficient growth of the young animal; it does not contribute to prepare the pre-ruminant to utilize solid diets.

Liquid feed is a sole source of nutrients for newborn calves until regular solid feed intake starts and the small intestine is the main site of liquid feed digestion. If small intestine development affects liquid feed digestion and nutrient absorption and consequently, calf growth and health in the first weeks of life, it may also affect solid feed intake and indirectly rumen development. Liquid feed type and composition may also influence plasma concentration of IGF-1, insulin and other growth factors, which play an important role in stimulation of rumen epithelial cell proliferation [34].

Calves offered only milk have relatively small increase in the capacity of the rumen in proportion to body weight. Numerous researchers have reported minimal rumen development in calves receiving solely milk or milk replacer even up to 12 weeks of age [10, 11, 13]. Thus feeding calves with restricted amounts of liquid feed and starter mixtures containing carbohydrates which are rapidly fermented to butyric and propionate acids is practiced to accelerate rumen development. Gorka *et al*. [17] found that total VFA concentration in the rumen fluid is lower in calves fed WM as compared with those fed MR and MR+ SB (Table 2).

Table 1: Parameters of rumen fermentation in calves fed different liquid feeds [17]

ACID	WM	MR	MR+SB
pH	5.2	5.3	5.3
Sum of VFA (m*M*/L)	75.2	76.2	86.1
Acetate (m*M*/L)	31.6	38.1	41.0
Propionate (m*M*/L)	29.5	28.7	34.4
Butyrate (m*M*/L)	8.7	5.7	6.8
Valerate (m*M*/L)	4.0	2.3	2.4

WM = whole milk; MR = milk replacer; MR+SB = milk replacer containing 0.3% sodium butyrate.

Low nutrient intake may contribute to the high rates of calf mortality and morbidity that plague the dairy industry [35]. The effect of increasing supply of milk to young calves includes higher weight gains and more natural behaviour in calves fed more milk [36, 37]. Disadvantages of providing more milk include reduced solid feed intake during the milk-feeding period [38] and slower rumen development [39, 40]. Other disadvantage of feeding limited amounts of milk is that growth rates are low compared with calves reared by the cow [41]. Calves are particularly susceptible to disease during the milk-feeding period, especially respiratory diseases and diarrhoea. Quigley *et al.* [42] reported a higher occurrence of diarrhoea in calves supplied higher levels of milk or milk replacers compared with restricted fed calves. Ruminal size of the milk-fed calf, regardless of rumen development, has been shown to increase proportionately with body size. Milk or milk replacer only fed calves had under developed rumen papillae and musculature [10]. Therefore, milk/milk replacer causes rapid and efficient growth but it does little to prepare the pre-ruminant calf for weaning or utilization of grain and forage based diets.

4.2 Calf Starter and Rumen development

Calf starter is a crucial link to proper ruminal development and successful weaning. It is also important to feed a good quality calf starter. A good quality calf starter should containing 18to 19% DCP and 75% TDN. Soybean meal is one of the most commonly used protein sources in calf starters. Calves fed the soybean meal based diet performed better than calves fed diet using other sources of protein. Calves receiving soybean meal had higher daily gain than calves fed starter with canola meal [43]. Calf starters should not be dusty, moldy or have an “off flavour”. Carbohydrate and protein sources, feed processing methods (biological, chemical, mechanical, or thermal), physical form of diet (textured or pelleted), and additives (direct-fed microbial, enzymes, and feed flavours) could affect the palatability of the starter Feed [44, 45].

The availability and intake of calf starter is important to calves prior to weaning. This will typically occur around six weeks of age. Feeding this starter early is critical as it has been shown that a four week old calf fed starter has a more developed rumen than a twelve week old calf that did not receive starter. The papillae length and thickness of rumen wall are significantly higher in 4 week old calves fed calf starters containing steam-flaked corn over those fed dry-rolled and whole corn when these corn supplements made up 33% of the calf starter [44]. The most commonly used grain in calf starters is corn because Grain-based starter diets that promote production of VFA (specifically butyrate) and an associated low rumen pH, are thought to trigger papillae growth in the rumen wall of calves. Corn gave the best live weight gains. Other ingredients are also used as carbohydrates source for example cane or sugar beet molasses. Calf starter commonly contain 5 to 12% liquid molasses to increase palatability minimize particle separation and decrease dust [8].

However, a high concentration of molasses has been shown to decrease DMI, may induce palatability problems, reduce average daily gain and increase the incidence of scouring in calves [44]. Also, a good quality calf starter has an easily digestible fiber source that will prevent parakeratosis, or a build-up of dead cells on papillae that block absorption of nutrients. To improve intake of energy, calf starter can be supplemented with fat. The inclusion of 7.3% fat in the starter decrease starter intake after weaning and did not improve ADG. Calf starters contain a feed additive which helps prevent coccidiosis. To earn the most money and grow calves the most efficiently, calves need to be fed a calf starter and water in the first few weeks of life.

Table 2: Nutrient Recommendation for Dairy Calf [45]

Nutrient	Amount (%)
Crude Protein	18
Fat	3.0
Total digestible nutrient	80.0
Ca	0.6
P	0.4
Metabolizable energy (kcal/kg)	3.11
Vit.A (IU/Kg)	2200
Vit.D(IU/Kg)	300
Vit.E(IU/Kg)	25

4.3 Solid Feeds and Rumen development

Ingestion of solid feed is necessary to stimulate rumen development in the young calf as it facilitates the development from a pre ruminant to a functioning ruminant. Solid feeds, unlike liquid feeds, are preferentially directed to the reticulo-rumen for digestion [23]. The rumen must possess sufficient physical capacity along with functionally active microbial population, and an efficient absorptive surface to effectively utilize starter rations. A smooth transition from liquid feed (milk or milk replacer) to solid feed (grains or forage) is a key factor in minimizing mortality and morbidity losses with diseases and increasing daily weight gains [46], as well as in minimizing weight loss and distress at weaning [47]. Calves start consuming small amounts of solid feed at about 14 days of age [45]. Solid feed can consist of concentrates or forages. Solid feed especially concentrate or high carbohydrate diets, stimulate rumen microbial proliferation and volatile fatty acid production, which initiate rumen development.

Concentrates have the greatest effect on rumen development. Intake of solid feed increases quickly when milk ration are reduced [39]. Restricted amounts of liquid feed and ad libitum solid feed intake positively affect development of rumen weight, volume and function in calves [48]. Solid feed intake from first day of life increases solid feed intake and can positively affect development of rumen microflora, rumen fermentation as well as its epithelium. If calves are early weaned (3–4 weeks of age) special attention should be given to the composition and structure of solid feed offered, because it is the main stimulator of rumen development [49]. Diaz *et al.* [37] reported that in the absence of solid feed, calves consumed bedding material, suggesting a growing hunger for solids as calf’s age.

4.4 Forage feeding and Rumen development

Maintenance of a higher ruminal pH supports microbial populations typically associated with forages, which in turn shifts volatile fatty acid production from butyrate and propionate to acetate. Highly fibrous feeds stimulate saliva production during chewing and rumination. The saliva provides urea and minerals, such as sodium bicarbonate that help maintain normal rumen microbial growth and development. However, these feeds do not provide sufficient amounts of the volatile fatty acids (VFA) needed for development of the rumen mucosa. In addition, these feeds may not contain sufficient energy and protein to meet the requirements of a rapidly growing calf. Roughage fermentation may not stimulate development of rumen epithelium enough when compared to calf starter [34].

Roughage or forage feedstuffs are important to promote the growth of the muscular layer of the rumen and to maintain the health of the epithelium [32]. Forages appear to be the primary stimulators of rumen muscularization development and increased rumen volume. Forage increases the ability to maintain a higher ruminal pH, due to a larger particle size and higher fibre content [49]. Although forage intake contributes less to rumen papillae development, forage intake promotes rumination and maintains the integrity and health of the rumen wall [50].

4.5 Chemical composition of feeds and Rumen development

Rumen development is stimulated by volatile fatty acids, primarily butyrate and propionate produced by micro biota of the rumen. The chemical composition of feed and end products of microbial fermentation have greatest influence on epithelial development [26]. Butyric acid provides energy for rumen development through thickening of the rumen wall, formation of papillae, and increasing capillary development [51]. However, acetic acid and propionic acid are well absorbed by the rumen wall and provides energy for growth of the calves. Amongst the three volatile fatty acids produced in the rumen 90% of the butyrate, 50% of the propionate and 30% of the acetate are metabolized by the gut [52]. Ruminal ketogenesis is characteristic of a mature rumen. Any butyrate not needed by the rumen is oxidized and transported into the bloodstream as β-hydroxybutyrate (BHBA). Increasing levels of blood BHBA in calves signify increasing ruminal mass and cell number and indicate increasing ruminal development and maturity. The primary source of butyrate in the rumen is microbial digestion of starch [25]. Fermentation products in the rumen such as volatile fatty acids particularly butyric acid are the main stimulators of rumen epithelium development [16]. Concentrate/diets containing cellulose, casein, and minerals increase the rate of rumen development when compared to forage sources.

When the calf consumes concentrate the rumen papillae will grow in size by the influence of starch that is converted by microorganisms to the volatile fatty acid (VFA) butyrate, which shifts the rumen into a light acid condition [2]. The microbial flora in the rumen also starts to multiply and develop so they can produce energy in form of the VFA acetate, propionate and butyrate. Volatile fatty acids, and especially butyrate are known to stimulate the papillae development, accelerates rumen motility and muscle development [13, 48]. Hence, length and density of papillae are good parameters to determine the development of the rumen.

4.6 Grain processing and Rumen development

Grain processing influences rumen VFA production, rumen pH, and rumen ammonia level. However, they are less influenced when forages were incorporated into the ration. Heat processing of grains has been shown to increase ruminal propionate production, whereas ruminal butyrate production appears to be enhanced by physical processing. Starch availability and digestibility is highest in steam-flaked grains, followed by finely-ground, then dry-rolled grains, and is lowest in whole grains [53]. Stimulation of rumen motility occurs by the same factors, particle size and effective fiber, in the neonatal ruminant as in the adult ruminant [54]. Different methods and extent of grain processing also have been reported to influence DMI. Highest intakes have been observed in diets containing dry-rolled grains, followed by whole, steam-rolled, and steam flaked grains, with finely ground grains resulting in the lowest intake. Mechanical and chemical alterations during processing increase surface area exposure and improve ruminal, intestinal and total tract starch digestibility of seed grains [55]. Grain particle size influences ruminal environment, VFA production, and papillae structure and function. Owens (2005) [56] conducted an experiment to study the impact of various processing techniques on changes of maize and its fermentation into rumen and the results are summarized in the Table 3.

Table 3: Impact of various processing techniques on changes of maize and its fermentation into rumen [56]

Processing	Reduces particle size	Disrupts Starch Granules	Increases fermentation rate
Dry rolling	+	-	++
Grinding	+++	-	++
Steam flaking	++	+	+++
Extrusion	-	+	++
Pelleting	-	-	+
Ensiling	+	-	++

* The number of + shows the degree of processing effect

4.7 Purified salts

Purified salts like sodium butyrate (NaB) or calcium butyrate (CaB) had the greatest effect on rumen epithelial development, followed by sodium propionate, sodium acetate and glucose had minimal effects. Salts of butyric acid such as sodium and calcium butyrate are used instead of butyric acid. Feeding calf starter containing NaB as purified salt may positively affect live weight gain, weight at weaning, and feed conversion efficiency during pre-weaning. The advantage of salts over free acids is that they are generally more stable and less odour and easier to handle. Hu, Z. and Guo, Y. (2007) [57] found that supplementing sodium salt of butyrate in milk replacer/starter may positively affect the stomach and small intestinal development in newborn calves. Similarly, Guilloteau *et al.* (2010) [58] reported that supplementation with NaB resulted in increased nutrient digestibility, stimulation of digestive enzyme secretion (in particular chymotrypsin and lipase), enhancement of proliferation, differentiation and maturation, reduction apoptosis in the enterocytes and modification of the intestinal luminal microflora and an improvement of the epithelial integrity and defence systems. It also stimulated intestinal cell proliferation, villus growth, and digestive enzyme activity and positively affected calf performance and health [59]. Quigley *et al.* [60] found that sodium bicarbonate at 3% increased rumen pH and acetate while decreasing propionate levels but had no effect on intake or ADG. May be the actual stimulant for epithelial development is the increase in production of butyrate and propionate/a decreased ruminal pH concomitant with stronger ruminal acid production, or a combination; concentrates appear to result in greater rumen epithelial development than forages. This concept is demonstrated in Table 3, which shows the marked effects of milk, milk and grain, or milk and hay in rumen development of 6 week old calves.

Table 4: Effect of various dietaries on development of the rumen [42]

Serial no.	Material	Effect on rumen development
1	Milk	+
2	Acetate	++
3	Propionate	+++
4	Butyrate	++++
5	Grain	+++
6	Hay	-
7	Plastic Sponge	-

4.8 Effect of physical form of feed on Rumen Muscularization and Volume

Feed physical structure has the greatest effect on development of rumen muscularization and volume. Large particle size, high effective fiber content, and increased bulk of forages or high fiber sources physically increase rumen wall stimulation, subsequently increasing rumen motility, muscularization, and volume [26, 49]. Increases in rumen muscularization and volume have occurred independently of epithelial development. Inert materials (sponges, toothbrush bristles or bedding) were found ineffective for stimulating papillae growth, but capable of significantly increasing rumen capacity and muscularization [61]. The solid feeds other than bulky feedstuffs or forages are effective method to influence rumen capacity and muscularization. Coarse/moderately ground concentrate increases the rumen capacity and muscularization more than finely ground/pelleted concentrate diet. This shows that various processing methods can positively affects the capacity of concentrates to stimulate rumen capacity as well as muscularization. Hence, concentrates with larger particle size may be the most desirable feedstuff for overall development of the rumen, due to their potent capacity to stimulate epithelial development, rumen capacity, and rumen muscularization development. Increasing availability of feed by-products through various processing technologies, development of better feed additives, and calf starter contains varied particle size provides the new areas for research in the field of developing various nutritional strategies for early rumen development.

5. Conclusion

It is well established that rumen liquor, bacteria, motility and absorptive ability are developed before rumen develop or it develop rapidly when calf begin to consume dry feed. Therefore, the most important factor determining rumen development is dry feed intake. Because grains are fermented to propionate and butyrate, they are a good choice to enhance the early rumen development. Similarly, early and aggressive feeding of calf starter as per the requirement of developing young calve is the key to good and early rumen development. The growth promoting agents for ruminal papillae are not the ruminal microbiota alone or dry feed alone. Rather, it is the fermentation end product butyrate is responsible for the growth of ruminal papillae papillae. Feeding calves with restricted amounts of liquid feed and starter mixtures containing carbohydrates which are rapidly fermented to butyric and propionate acids is practiced to accelerate rumen development. Solid feed especially concentrate or high carbohydrate diets, stimulate rumen microbial proliferation and volatile fatty acid production, which initiate rumen development. Forages have an increased ability to maintain a higher ruminal pH, due to a larger particle size and increased fibre content. The higher pH of rumen favours microbes associated with forage, which shifts the volatile fatty acid production from butyrate and propionate to acetate. Purified salts of butyrate (sodium butyrate, calcium butyrate) had the greatest effect on development of rumen epithelial, followed by sodium propionate, sodium acetate and glucose had least effect. Excessive processing of grain reduces the digestibility of dietary fiber. Although, much is known about rumen development but several areas require additional study. The development of new technologies is necessary to enhance early rumen development which will increase the income of dairy and beef producers.

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