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Physical Form of Calf Starter: Applied Metabolic and Performance Insights

Review Article

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ABSTRACT

The objective of this review article was to evaluate and elaborate on dairy calves' metabolic and growth responses to different physical forms of dry starter feed in relation to forage in the pre-weaning period. In addition, practical guidelines were discussed for on-farm uses. Apart from chemical composition, physical structure of solid feeds can influence nutrient intake and growth of young calves. Starter feed intake is essential for the timely development of a functional rumen and successful weaning transition with minimized weaning distresses. The calf starters produced commercially include pelleted, mashed, and texturized forms. Numerous studies have investigated the effects of physical form of starter and feed particle size on dairy calf performance. However, the results have been inconsistent. In addition, forage particle size in dairy calf diets has not been precisely determined and more investigations seem to be required. It is believed that alterations in the physicochemical properties of feed ingredients during processing influences rumen digestion that can partially explain the inconsistencies in research outcomes. Calf starter comprises large amounts of grains with different starch content and varying degradation dynamics, thereby differently affecting the rumen environment and calf growth. Grain type and processing method may interact with other starter ingredients such as forage and high-protein meals, making it difficult to decide which processing method or physical form would be optimal or preferred. Moreover, the first three weeks of calf life is thought to be more critical than the rest of the pre-weaning period, which requires distinct nutritional and management considerations. Encouraging calves to consume solid feed intake in the early ages may be a multi-advantage practice to ensure that calves eat more starter during the rest of the pre-weaning period. Accordingly, physical form of starter diet might affect solid feed intake differently during these two distinct pre-weaning periods. In conclusion, understanding the effects of feed processing on calf rumen physiology and metabolism may provide practical outlooks for optimal preparation of starter diets for calves at different stages of growth.

KEY WORDS dairy calf, growth, particle size, physical form, rumen physiology, starter feed.

INTRODUCTION

After birth, the newborn calf's digestive tract undergoes significant physiological changes to adapt to the extra-uterine environment and nutrition (Kirovski, 2015; Meale *et al*. 2017). The first two or three weeks of life as well as weaning transition are the most critical stages of dairy calf life with tremendous adaptations in immune system, metabolic status, and physical structure of the gastrointestinal tract and splanchnic tissue (Nikkhah and Alimirzaei, 2022a). In other words, a successful weaning program requires well-developed and functional gastrointestinal tract and splanchnic metabolism (Baldwin *et al*. 2004). In addition to milk feeding strategies, chemical and physical form of starter diet is hypothesized to impact rumen physiology and growth of calves in both pre- and post-weaning periods. Different processing methods of calf starters with or without hay supplementation may affect rumen fermentation patterns, thus causing the rumen environment to be metabolically and anatomically different. Smooth transition from liquid to solid feed has been recognized as a key factor influencing post-weaning performance (Khan *et al.* 2016). Keeping the post-weaned heifers' weight gain about at least 800 g/d to reach 350 kg body weight at 14-15 months of age (time of breeding) is as ultimate goal of commercial heifer rearing (Akins, 2016). It is important to mention that breeding time could be reduced as weight gain increases, resulting in enhanced productivity. In addition, a positive relationship exists between future milk yield and feed intake of calves during weaning period (Soberon *et al.* 2012).

Starter feeds are commercially available usually in ground, pelleted, and texturized forms that can differently impact the rumen environment and calf performance. It has been reported that calves fed ground starter feed had shorter papillae and deceased surface area when compared with calves fed chopped hay and rolled grains (Beharka *et al.* 1998). Fine grinding was found to be involved in rumen parakeratosis (Beharka *et al.* 1998). Starter particle size exceeding 1190 µm was suggested to reduce mashed diets' negative effects (Porter *et al.* 2007). Ghasemi Nejad *et al.* (2012) found that compared with mashed starter, pelleted or texturized starters could enhance neonatal Brown Swiss calves performance. In contrast, in a recent study, authors found no effects of starter particle size (pelleted *vs.* ground starter) with or without hay inclusion on rumen pH, feed intake, and weight gain of calves during 63 d of the experimental period (Leão *et al.* 2020). Forage supplementation may have an interaction with particle size of the starter diet. It seems that the inclusion of even small amounts (5-10%) of forage to calf starter would alleviate the rumen pH decline following highly ground starter intake (Xiao *et al.* 2020). Moreover, decreased non-nutritive oral behavior was observed when the particle score of alfalfa hay was increased from 1mm to 3 mm in calves fed mashed starter (Nemati *et al.* 2015).

A recent meta-analysis (Ghaffari and Kertz, 2021) revealed that texturized starter diet might improve calf performance compared with ground or pelleted starters. However, these authors indicated that as many discrepancies exist amongst studies, scientific evidence is lacking to suggest a preferable starter form. The inconsistencies observed between studies can be partially described by variations in processing methods, grain source, milk feeding programs, weaning age, source and particle size of forage, and other management practices. Most importantly, during the first three weeks of life, when the calf's digestive tract and immune system are adapting to the extra-uterine life, newborn calves respond to milk feeding levels (*ad libitum vs.* restricted) differently (Curtis *et al.* 2018; Nikkhah and Alimirzaei, 2022a; Nikkhah and Alimirzaei, 2022b). In the case of calf starter feeding, it is not clear whether in the first three weeks of age and the rest of pre-weaning period, the calves' responses to different forms of starter are the same or not. Such gaps in the starter nutrition should be investigated in future studies. Consequently, the current review will focus on the physiological effects of processing and physical form of starter on pre-weaning calves' metabolism and growth. Also, this article aggregates the literature findings to provide scientific suggestions with practical insights regarding the use of different forms of starter feeds. Furthermore, a scientific perspective for phase feeding of newborn calves (the first three weeks vs. the rest of the pre-weaning period) will be presented. Future directions of research will also be suggested.

The importance of solid feed in post-modern dairy calf nutrition

Dairy calves raising principles seem to be changing towards natural raising similar to when they are raised with their mothers and weaned gradually. In this situation, calves receive whole milk from their dams about approximately 10-12 L/d, which is much more than the amount in the traditional rearing systems where they are artificially raised in individual pens or hutches and fed through bucket twice a day and about 4 L/d (Khan *et al.* 2011). It has been demonstrated that feeding higher amounts of milk in early life has growth and health benefits when compared to traditional milk feeding (Khan *et al.* 2011; Alimirzaei *et al.* 2020). It is believed that such changes in calf feeding systems may influence the digestive tract physiology, animal behavior, and gut microbiology (Meale *et al.* 2017). Moreover, feeding higher milk levels might interact with solid feed intake and chemical and physical forms of the starter diet. With regard to the inverse relationship between milk and starter intakes, allocating higher amounts of milk to calves may reduce starter intake and cover its beneficial effects (Khan *et al.* 2011). As shown by Mirzaei *et al.* (2020), however, step-down method of weaning could overcome such negative effects of the higher milk allowance. Maximizing starter intake is crucial for timely rumen development, and hence, for successful weaning transition (Khademi *et al.* 2022). Increased solid feed intake in the pre-weaning period has been suggested as a key factor involved in weaning success and alleviating weaning distress (Nikkhah and Alimirzaei, 2022c; Nikkhah and Alimirzaei, 2022d). Despite the negative relationship between milk and starter intakes (Khan *et al.* 2011), boosting concurrent intakes of milk, starter, and water intakes has been proposed for optimizing pre-weaned calves' growth and health (Nikkhah and Alimirzaei, 2022d). In a study to evaluate the role of individual personality of calves on weaning age and growth, the calves that started to eat the solid feed earlier (early learners) had decreased weaning age when compared to their late learner peers (Neave *et al.* 2019). In addition, traits such as vitality at birth, drinking ability, and exploratory-active characteristics were associated with feed intake, behavior, and finally calf performance. It is important to note that 12 L/d milk replacer was fed up to 30 d of age from automated calf feeders, and calves were weaned according to their starter intake (approximately 1300 g/d) (Neave *et al.* 2019). Such studies may provide insight that improved well-being and starter feed intake can coincide with higher amounts of milk consumption that may ultimately enhance pre-weaning calves' health and performance.

Chemical and physical forms of starter diet play critical roles in solid feed intake and subsequently in the rumen development and growth of calves. Whether the physical form of starter feed could affect dry matter intake in high milk fed calves would be of health and economic importance. Recently, the effects of physical form of starter feed and milk allowance on dairy calf performance were investigated (Jafari *et al.* 2020). The results showed no interactions between milk quantity and physical properties of starter diet. In another study (Van Niekerk *et al.* 2020) carried out to evaluate how feeding different amounts of milk replacer and corn grain form (flaked *vs.* whole) would affect feed intake and performance of dairy calves, corn processing had no significant effects on starter intake, body weight, and average daily gain of calves. The authors concluded that milk replacer feeding rate was a more important factor than corn processing in affecting calf performance (Van Niekerk *et al.* 2020). Interestingly, the calves fed a higher *vs.* lower amounts of milk replacer had lower weight gain in the week after weaning (week 7), reflecting impaired rumen development in these calves. It has been demonstrated that buffalo calves on high milk with late weaning (84 d of age) had better growth performance than did calves fed low volumes of milk with weaning in early ages (56 d of age) (Abbas *et al.* 2017). In agreement with these results, Klopp *et al.* (2020) concluded that weaning distress in calves fed higher amounts of milk can be alleviated through gradual weaning process (step down for 21 d). Starter intake at weaning is likely an important benchmark related to the future milk yield of dairy heifers (Heinrichs and Heinrichs, 2011). As such, rumen development and solid feed consumption at weaning should be considered with more details when higher volumes of milk are fed to pre-weaning calves. Studies that have investigated the relationships between feeding high amounts of milk or milk replacer and physical form of starter diet are limited. Thus, more research is needed to define what type of processing method or form of starter diet should be used to optimize pre- and post-weaning performance of dairy heifers.

In addition to the physical form of the starter diet, it seems that the amounts and physical form of forage included in the modern calves' rations play an important role in their feed intake and growth (Ghaffari and Kertz, 2021). In high producing dairy cows' diets, forage (hay or silage) is used for different purposes including rumen filling properties, promotion of chewing activity, and stabilization of rumen pH. Including forage into young calve' diets has been reviewed recently (Nikkhah and Alimirzaei, 2022c).

The authors described that sub-acute ruminal acidosis (SARA) occurs following highly fermentable carbohydrates consumption; thus, provision of forage to pre-weaned calves could mitigate the adverse effects of SARA on calf's feed intake and growth. It has been shown that including 10% of chopped alfalfa hay into the ground calf starter stabilized rumen pH and stimulated rumen development and growth (Pazoki *et al.* 2017). Rumen environment and calf growth may be influenced remarkably by the rumen pH. The durable rumen pH decline must be prevented. Accordingly, providing appropriate amounts of forage with optimized particle size for pre-weaning calves would be recommended. Calf studies investigating the physical form of forage are rare and the young calf's requirements for physically effective neutral-detergent fiber (NDF) have not been clearly defined.

Feed processing and nutrient utilization

Calf starters are mostly presented in processed forms to increase intake and productivity. Cereal grains including corn, barley, oat, sorghum, and wheat comprise the major portion of dairy calf' starter feeds as energy sources. Grains can be processed mechanically, thermally, chemically, or with combinations of these procedures. Different methods are available for processing feed ingredients which can be divided into two main categories including cold and hot methods (Kellems and Church, 2011). Grinding and rolling are common examples of cold processing methods, whereas reconstitution and steam-flaking are considered as hot methods. During cold processing, the physical structure of grains changes. During hot processing methods; heat, moisture, and maybe pressure are involved in processing procedures. Pelleting, steam-rolling, steam-flaking, extruding, and roasting are considered as important hot processing types used in the calf starter feed industry. It seems that in heat-based processing methods, chemical composition of grain is altered. For instance, in steam-flaking method, the grain is exposed to high-moisture stream for a longer period of time (15-30 min) than steam-rolling (5-13 min), causing gelatinization of starch which is more available for animals

(Kellems and Church, 2011; Qiao *et al.* 2015). Moreover, chemical treatments with ammonia, sodium hydroxide as well as formaldehyde are used commonly to process starter ingredients before they are fed.

The nutritive value of grains can be significantly influenced by processing (Mathison, 1996). It has been reported that processing can improve nutrient digestibility in both ruminants and monogastric animals (Ghasemi Nejad *et al.* 2012; Rojas and Stein, 2017; Makizadeh *et al.* 2020). In a study conducted to evaluate three heating methods of steam-flaking, microwaving, and roasting on barley grain digestibility in the rumen and total digestive tract, the results showed greater rumen degradability of barley grain with steam-flaking than the other treatments (Shirmohammadi *et al.* 2020). As such, the authors concluded that heat processing improved total digestive tract digestibility of barley grain. In another study, organic matter digestibility and nutritional and energetic values of cereal grains (maize, wheat, and rice) were improved by steam-flaking (Fu-Giang *et al.* 2014). Overall, total-tract digestibility in the pre- and post-weaning periods seems to be influenced by processing methods and physical forms of starter diet (Quigley *et al.* 2018). Although processed starter feeds are likely more digestible than unprocessed feeds, it seems that texturized and pelleted starters' digestibility depend on calf age. It has been demonstrated that calves fed texturized starter tended to have increased dry matter, starch, organic matter, NDF, acid-detergent fiber (ADF), and crude protein digestibility during 6-8 weeks of age.

However, digestibility of texturized ration decreased for the next stage of the study from d 57-112 (Quigley *et al.* 2019). Others found no differences between texturized and pelleted starter feeds on nutrient digestibility (Bach *et al.* 2007; Ghasemi Nejad *et al.* 2012). Notable, grain particle size before pelleting is important, as fine particles may predispose animals to ruminal acidosis (Ebrahimi, 2020). The rumen pH is a final frontier of feeding programs in both young and adult ruminants. The likelihood of the rumen pH decline must be considered when highly fermentable processed feeds are fed. Accordingly, the effectiveness of forage inclusion into calf starter is more profound when the starter is composed of highly fermentable processed grains (Ghaffari and Kertz, 2021).

It is believed that both physical and chemical processing methods increase the surface area, providing appropriate chances to the rumen bacteria for attaching to and accessing the endosperm of grains (Huntington, 1997). Attachment is the primary important phase in initiating microbial digestion. The pericarp layer of cereal grains (Figure 1) resists against microbial attachment and subsequent penetration into the internal layers (McAlister and Cheng, 1996).

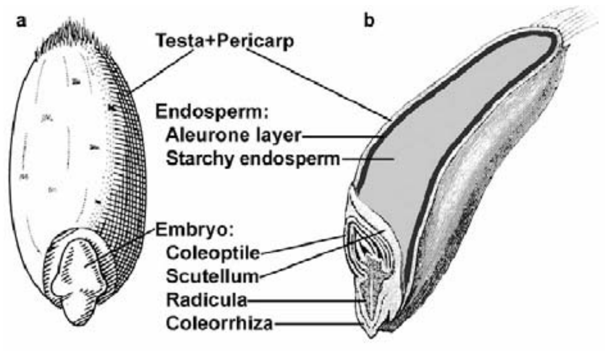

Figure 1 Pericarp and endosperm layers of cereal grains (Aslam *et al.* 2018)

It has been reported that digestion rate of grain's endosperm is related to grain species (McAlister and Cheng, 1996). For instance, starch granules in corn and sorghum grains are surrounded by a dense protein matrix, which makes it difficult for the rumen bacteria to penetrate. In contrast, floury nature of barley and wheat grains allows bacteria to attach and digest starch more quickly (McAlister and Cheng, 1996). In addition to the mechanical damage of the pericarp layer to increase grain digestibility, gelatinization of starch during pelleting and flaking could enhance grain digestibility (Ebrahimi, 2020). In this case, pre-pelleting particle size of grains is important for the pellet durability and digestibility. The pre-pelleting particle size can vary among animal species and grain types (Ebrahimi, 2020).

Also, steam-flaking method was found to be more profitable for corn and sorghum grains than for barley and wheat grains (Armbruster, 2006). Destroying the protein matrix that surround starch granules occurs during steam-flaking. Overall, the increased starch and non-starch organic matter digestibility resulting from steam-flaking and subsequent gelatinization causes elevated net energy value of corn grain (Ebrahimi, 2020).

Starter physical form with respect to the rumen environment, intake, and growth

Traditionally, limited amounts of milk were fed to calves to promote solid feed intake and early weaning (Kertz *et al.* 1979). However, by clarifying the fact that providing higher levels of milk or milk replacer can lead to greater weight gain in the pre-weaning period and more milk yield subsequently in the first lactation (Soberon *et al.* 2012), dairy calf nutrition management has changed over the years. Accordingly, extended gradual weaning has been proposed to increase solid feed intake and successful weaning transition in high milk fed calves since it is necessary for developing a functional rumen (de Passille *et al.* 2011; Nikkhah and Alimirzaei, 2022a; Nikkhah and Alimirzaei, 2022d). Although an inverse relationship between milk and though an inverse relationship between milk and starter intake has been indicated in the literature (Khan *et al.* 2011), maximizing starter intake in high milk fed calves should be considered as a strategic management decision. Recently, concurrent increases in milk, starter, and water intake have been suggested for boosting pre-weaning calves' performance and farm productivity (Nikkhah and Alimirzaei, 2022d). The importance of early starter consumption on rumen microbiota and development has been recently investigated (Chai *et al.* 2021). As such, understanding the physiology of the rumen development with respect to the physical form of the calf starter may help scientists and producers integrate differently processed starter feeds with new milk feeding systems.

Establishing a functional rumen and transforming calves into ruminant animals is an ultimate target in commercial calf nutrition. Timely rumen development is a prerequisite for enhanced nutrient intake and feed digestion as well as successful weaning, and finally for optimal pre- and post-weaning growth of replacement heifers. It has been reported that early solid feed intake influences rumen development and may possess long-term effect on productivity and longevity of dairy cows (Diao *et al.* 2019). The rumen development should be considered both metabolically and physically. Numerous factors including liquid feed, starter feed, forage provision, and physical form of both starter and forage could affect the rumen development (Khan *et al.* 2016). Starter feeds tend to produce higher levels of propionate and butyrate when they are fermented in the rumen, whereas fibrous feeds tend to produce higher levels of acetate (Khan *et al.* 2016). Butyrate and propionate are the primary fuels for the rumen epithelial cells, promoting rumen papillae development. Total concentration of volatile fatty acids (VFA) in the rumen can be influenced by many factors such as starch source, dietary levels, and grain processing method (Khan *et al.* 2016). As noted, grain processing (grinding, pelleting, rolling steam-flaking, and other processing methods) disrupts the protein matrix and predisposes the starch granules to microbial attack (Huntington, 1997).

Anatomical and microbial alterations were found for calves fed ground and unground diets (Beharka *et al.* 1998). Shorter papillae and decreased surface area were observed for calves fed a ground diet relative to those fed an unground diet. In addition, the rumen pH and the number of cellulolytic bacteria were lower for the ground diet fed calves (Beharka *et al.* 1998). Lower ruminal pH may describe decreased number of cellulolytic bacteria. In a study conducted to evaluate the effects of different physical form of starter on calf performance, the calves fed a texturized starter (rolled barley, corn, and oat) had lower rumen pH than those fed a pelleted starter supplemented with wheat straw (Terre *et al.* 2015). The authors concluded that the rumen pH was similar to that of the pelleted starter with straw supplementation when corn was offered as whole grain in the texturized starter (Terre *et al.* 2015). In another study comparing a pelleted starter diet with a coarsely ground diet with or without alfalfa hay, decreased rumen pH was observed for the pelleted starter fed calves (Nilieh *et al.* 2018). However, supplementing starter feeds with forage mitigated the adverse effects of the declined rumen pH on feed intake and growth performance. According to the results of Nilieh *et al.* (2018), rumination time was increased by including alfalfa hay, which would result in higher ruminal pH. In another study comparing pelleted and ground starters, no significant differences were found between treatments on rumen pH, feed intake, or other rumen and performance parameters (Leao *et al.* 2020). Such controversies in the results between international studies can be attributed to the different manufacturing methods in processing, and to the variations in ration composition. However, it seems that provision of forage alongside highly fermentable processed feeds may help stabilize ruminal pH. It has been shown that calves supplemented with corn silage had elevated starter intake, rumen pH, average daily weight gain and final body weight in comparison with unsupplemented calves (Mirzaei *et al.* 2015).

Studies on the effects of starter intake on growth of calves fed different forms of calf starter have reported varying results. In a recent study, finely ground, dry-rolled, and crumbled corn were fed and decreased feed intake was observed for the finely ground fed calves (Malekkhani *et al.* 2022). Moreover, feeding the crumbled diet increased total-tract starch digestibility relative to other two treatments. There were no significant differences between thermal and mechanical processing methods. This result further indicates that calves need solid materials rather in course form. In a study conducted by Bateman *et al.* (2009), feeding high moisture corn based starter to calves caused lower average daily gain and feed intake when compared to feeding a textured starter. In addition, decreased weight gain was observed for calves fed pelleted starters than for calves fed unpelleted feeds (Newman and Savage, 1938). As noted, such responses can be partly explained by reduced rumen pH and decreased feed intake. In another study, average daily gain, metabolizable energy intake, and starter intake were greater for textured starter fed calves (Omidi-Mirzaei *et al.* 2018). Of note, adding wheat straw to the starter diet increased the average daily gain of calves in the post-weaning period. In general, as noted by Ghaffari and Kertz (2021), textured calf starter may possess benefits for pre-weaning calves. However, it seems that the overall effectiveness of processing methods would be dependent on starter fermentability, calf age, and milk feeding programs.

For instance, Hill *et al.* (2019) reported that calves under 2 months of age fed textured starter had no need for hay supplementation.

Future directions of investigation

With emerging new milk feeding methods (intensified *vs.* conventional), maximizing calf starter intake is a challenge for the dairy industry. The dairy calves' digestive tract physiology is totally different in the first weeks of life *vs.* the rest of the pre-weaning period. Increasing the amounts of milk in the early stages of life can lead to greater weight gain; however, solid feed intake may be jeopardized. Thus, discovering the proper processing method to optimize solid feed intake in the first few weeks of life should be pursued in future studies. In addition, the comparative effects of different forms of calf starter during the three distinct phases of growth including 1) the first three weeks of life, 2) the rest of the pre-weaning period, and 3) the post-weaning period should be investigated. Moreover, the physical form of different forage sources may be another area of research. Furthermore, more studies are warranted to determine the optimum particle size of forages in high milk fed and gradually weaned modern dairy replacements.

CONCLUSION

Processing dairy calf's starter ingredients may increase starter digestibility and may improve calf performance. However, determining that which processing method and form of starter diet is preferable would totally dependent on farm management quality and milk nutrition programs. Of importance, when highly fermentable processed feeds are used in starter preparation, producers should pay attention to within-day and inter-day feed intake patterns of calves as an indicator of rumen pH fluctuations. Indeed, processing can be useful if fluctuations in the rumen pH decrease. As such, the practically effective physical forms of starter can be complemented by quality forage sources to promote rumination and help stabilize rumen pH.

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