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Physically effective fibre in ruminant nutrition: A review

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Abstract
Ruminants require fibre in coarse physical form described as the "physically effective fibre" which has a significant effect over chewing and ruminal activity. Physically effective NDF (peNDF) is defined specifically as the fraction of fibre that stimulates chewing activity and is primarily related to the particle size. Increasing fibre content and physically effective NDF enhances saliva flow, acetate to propionate ratio, milk fat levels and maintains the rumen pH. An appropriate level of NDF and the particle size in the ruminant diet will increase the dry matter intake and its digestibility and has a positive impact over the ruminant performance. According to National Research Council (NRC), NDF content should be maintained at 25 per cent of dietary dry matter with at least 75% from forage. PSPS is commonly and routinely used separator to express the particle size distribution, and to calculate the content of peNDF. Till now no recommendations are given for the physically effective fibre due to lack of standards and validated technique to quantify the physically effective properties of fibre in the diet.

Keywords: Physically effective fibre, chewing and ruminal activity

1. Introduction
Fibre plays an important role in ruminant nutrition. Fibre is essential to maintain the animal health and is required to maintain an appropriate rumen function and physiology (Aghsaghali *et al.*, 2011) [12]. Fibre can be defined as the "indigestible and slowly digesting, or incompletely available, fractions of feeds that occupies space in the gastrointestinal tract" (Mertens *et al.*, 1992) [10]. Nutritionally, fibre has both physical and chemical attributes that are related to the mechanical processes of digestion (chewing and passage) and to enzymatic degradation associated with fermentation. Fibre content of a diet is usually expressed in terms of neutral detergent fibe and acid detergent fibre. ADF includes cellulose and lignin as the primary components and concentrations of ADF and lignin are correlated more with digestibility than with intake (Mertens *et al.*, 1997, Van Soest *et al.*, 1965) [11, 18]. NDF includes cellulose, hemi-cellulose, and lignin fractions of feeds and is more highly correlated with feed volume and chewing activity than ADF or CF (Mertens *et al.*, 1997) [11].
The description of the fibre content of a diet in terms of NDF and ADF is found to be inadequate and the neutral detergent fiber (NDF) is the most common method to estimate fiber. But ruminants require fibre in coarse physical form described as the "physically effective fibre" which has a significant effect over chewing and ruminal activity. Physically effective NDF (peNDF) is defined specifically as the fraction of fibre that stimulates chewing activity and is primarily related to the particle size (Merten *et al.*, 1997) [11]. Increasing fibre content and physically effective NDF enhances saliva flow, acetate to propionate ratio, milk fat levels and maintains the rumen pH. An appropriate level of NDF and the particle size in the ruminant diet will increase the dry matter intake and its digestibility and has a positive impact over the ruminant performance.
To assess the effect of "physically effective fibre" in ruminant ration certain parameters like chewing activity, ruminal pH, feed intake, and mik fat percentage can be considered (Kononoff *et al.*, 2003a) [7]. Since the concept of peNDF incorporates information on chemical NDF content and fractions of particles of the diet, it is considered to be more efficient in predicting rumen conditions (Mertens, 1997; Zebeli *et al.*, 2006) [11, 21].

2. Forage particle size and measurement of physically effective fibre
2.1 Forage particle size
Optimization of particle size (PS) of forages is an important feeding strategy in dairy cattle (Tafaj *et al.*, 2005) [17]. A fine PS will result in faster passage of ruminal digesta, providing fewer stimuli for chewing activity and ruminal contractions (Mertens, 1997) [11]. Small or fine PS will lead to reduced ruminal pH, depressed fibre digestion, feed intake and feed efficiency

(Tafaj *et al*., 2005) [17]. On the other hand it has been reported that, a moderate decrease of PS will promote ruminal digestion due to increasing available surface area for fibrolytic action of rumen bacteria (Kononoff, P.J. and Heinrichs, 2003b) [8].

Yang and coworkers observed an increase in the feed intake, increase in the nutrient supply to the high producing dairy cows with a moderate decrease in the PS. Lowering average particle size of forages decreases peNDF content and decreases physical effectiveness of ration (Stojanovic *et al*., 2011) [16]. Thus, optimization of forage PS is an important aspect in dairy cattle nutrition. However, practically it is difficult to determine the optimal forage PS.

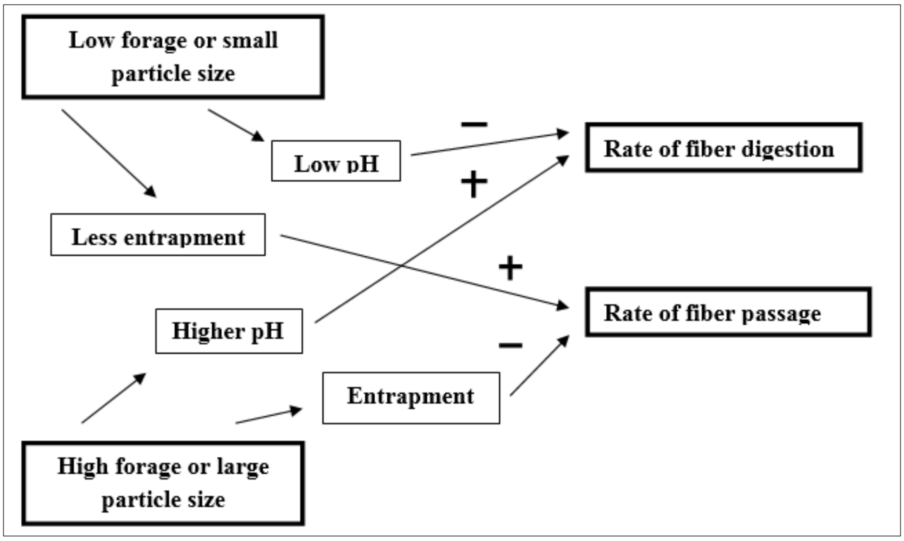

Fig 1: Potential interactions among forage level and particle size on rate of ruminal fibre passage and digestion (Grant *et al*., 1997)

2.2 Measurement of physically effective fibre

The procedures for measurement and expression of PS of forages or TMR are considerably different, which makes it difficult to give recommendations for PS in the diets of dairy cattle. In 1996 Penn state university developed a simple device that works on a low-cost procedure, which is now routinely used to evaluate feed particle size. The device was named after university and was called as Penn State Particle Separator (PSPS) (Lammers *et al*., 1996; Kononoff *et al*., 2003a) [7]. The original device was constructed out of two sieves measuring 19.0 and 8.0-mm, and later one more sieve measuring 1.18mm added and it was based on the S424 standard of the American Society of Agricultural Engineers (ASAE).

Compared to PS of forages at harvesting, by means of PSPS feed samples can be fractioned in different proportions of particles according to the feed proportion retained on each sieve and the pan (Kononoff *et al*., 2003a) [7]. PSPS can be used to calculate the content of physically effective NDF (peNDF) of the diet. Since peNDF incorporates information on chemical NDF content and fractions of particles of the diet, it is considered to be more efficient in predicting rumen conditions (Mertens, 1997; Zebeli *et al*., 2006) [11, 21].

The peNDF content of a feedstuff is calculated as the product of its NDF concentration and the physically effectiveness factor. The above calculation is based on the assumption that a hypothetical standard feed would be most effective if it contained 100 percent NDF and possessed a physically effectiveness factor of 100 percent, yielding a peNDF of 100 percent. In other words pef varies from 0, when NDF is not physically effective, to 1, when NDF is fully effective in promoting chewing and rumen buffering (Zebelia *et al.,* 2010) [22]. Thus, the estimation of peNDF is a function of the concentration of NDF and the physical form of the feed.

The first method of the calculation of peNDF consists of the sum of DM proportion retained on sieves of 19- and 8-mm of PSPS (Lammers *et al*., 1996) or as the sum of particles retained on sieves of 19-, 8- and 1.18-mm (Kononoff and Heinrichs, 2003a) [7] multiplied by the NDF content of the diet; Hence assuming uniform content of NDF throughout the fractions retained on the sieves. Another method of measuring peNDF content consists in measuring the fraction of NDF retained on the sieve 8 mm (peNDFN8-NDF), or 1.18 mm (peNDFN1.18-NDF) of PSPS. In fact, the latter is a more precise method in expressing the peNDF content of TMR, as this takes into consideration the differences that exist in NDF content among different particle fractions. However, given that both these methods have given similar rankings of the dietary peNDF contents (Yang and Beauchemin, 2006a; Rustomo *et al*., 2006), and that the measurement of peNDFN8 and peNDFN1.18 is a more practical and less costly procedure than the measurement of peNDFN8-NDF and peNDFN1.18-NDF, the first method would be more applicable on the farm.

Apart from the optimal amount peNDF, fermentability characteristics of diet have an influence on normal rumen conditions. The main drawback of the peNDF concept is that it doesn't take the differences in ruminal fermentability of various feedstuffs into consideration. This often results in inconsistent responses of ruminal pH to dietary peNDF and makes it difficult to quantitatively characterize the effects of peNDF on ruminal fermentation and production responses.

3. Influence of peFibre on performance of ruminants

To assess the effect of "physically effective fibre" in ruminant ration certain parameters like chewing activity, ruminal pH, feed intake, and milk fat percentage can be considered (Kononoff *et al.*, 2003b) [8].

3.1 Effect on chewing activity

Chewing activity is the one that determines the amount of saliva production and secretion. Chewing activity in turn is influenced by the type of forage, forage to concentrate ratio, forage intake and physiological status of the animal. The fibre content and the forage: concentrate ratio of the diet influences the intake limiting characteristics of diets like bulk density, digestibility, and rate of digestion, rumination time, total mastication time and passage of digesta from the ruminoreticulum. The fibre that promotes chewing is considered physically effective. Physically effective fibre increases chewing activity resulting in increased saliva flow that acts as a buffering agent in maintaining the rumen pH, acetate-to-propionate ratio, and milk fat levels. Mertens (1997) [11] reported a decrease in the chewing activity per kilogram of NDF because of reduction in the particle size.

Table 1

Feed and physical form	NDF	Total Chewing Activity		
	% of DM	Min/kg of DM	Min/kg of NDF	% reduction
Alfalfa hay Long	54	72	134	100
Chopped (3.8cm)	54	59	109	82
Bermudagrass hay Long	72	108	149	100
Chopped (3.8cm)	72	85	118	82
Alfalfa hay Long	53	62	117	100
Chopped (3.8cm)	53	44	84	72
Oat straw Long	84	163	194	100
Chopped	75	84	113	58
Ryegrass Long	65	90	139	100
Fine ground (1.2 cm)	64	19	29	21

The effect of particle size of forages on the chewing activity of cows. (Mertens., 1992) [10]

From the above table it is evident that the grinding forages or fine particle size can reduce the chewing activity to 20 to 60 per cent of that for long forage. Mertens (1992) [10] assumed an exponential relationship between theoretical length of cut and chewing activity and predicted that the chewing activity of forages with theoretical lengths of cut of 40, 20, 5, and 1 mm would be 80, 70, 50, and 25% respectively of that for long forage.

Forage particle size can affect the nature of feeding behavior. A constant rumen environment leads proper growth of rumen bacteria which is achieved by a consistent supply of nutrients. Recent works on physically effective fibre shows that the amount of material retained on the 19.0 mm sieve of the PSPS is best correlated to chewing activity and feed behavior. As ration particle size or effective fibre increases, the chewing activity and feeding time increases and this is due to an increase in the chewing rate or time spent per unit of dry matter consumed.

The relationship between particle size and chewing activity is not completely linear. Ruminants prefer coarse, longer and high-fiber particles and it greatly affect rumen fermentation (Kononoff *et al*., 2003b) [8]. There is a need to improve the practical understanding of forage particle size or physically effective fibre on feeding activity and behavior.

3.2 Effect on ruminal pH

Ruminal pH is a critical factor since it has a significant effect on the growth of rumen microbial population which in turn has an effect on the production of rumen microbial fermentation products and physiological function of rumen. Ruminal pH is mainly influenced by the intake of fermentable carbohydrates, rate of production, absorption and utilization of VFAs.

There exists a difference in the rumen pH at which certain functions are optimized eg, microorganisms which prefer starch require a pH ranging between 5.8 to 6.4 and fibrolytic bacteria are active at 6.2 to 6.8. To accommodate all these needs, normal feeding practices should maintain a pH range between 5.8 to 6.4. A proper inclusion of physically effective fibre will result in maintaining the pH between 5.8 to 6.4. Ruminal pH can be used as an indicator in assessing ruminal health and optimal function.

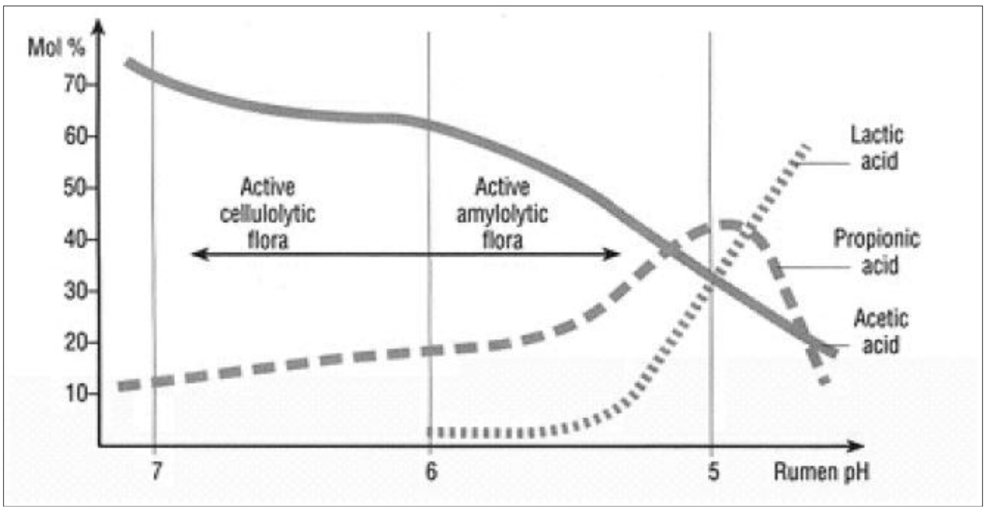

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Fig 2: Ruminal fermentation as a consequence of adaptation due to pH response

Diets containing more of fermentable carbohydrates or non fibre carbohydrates (NFC), will lead to production of more organic acids and on the other hand peNDF will increase the chewing activity resulting in more saliva secretion. Balance diets having optima level NFC and peNDF can be accomplished by combining diet components in TMR rather than feeding forage and concentrate separately. Erdman (1988) reported to have no relationship between ruminal pH and milk fat percentage, and observed a linear relationship between ruminal pH and ADF concentration. Pitt and coworkers used data from sheep, beef cattle, and dairy cattle and observed a better relationship between peNDF and pH than between NDF and pH.

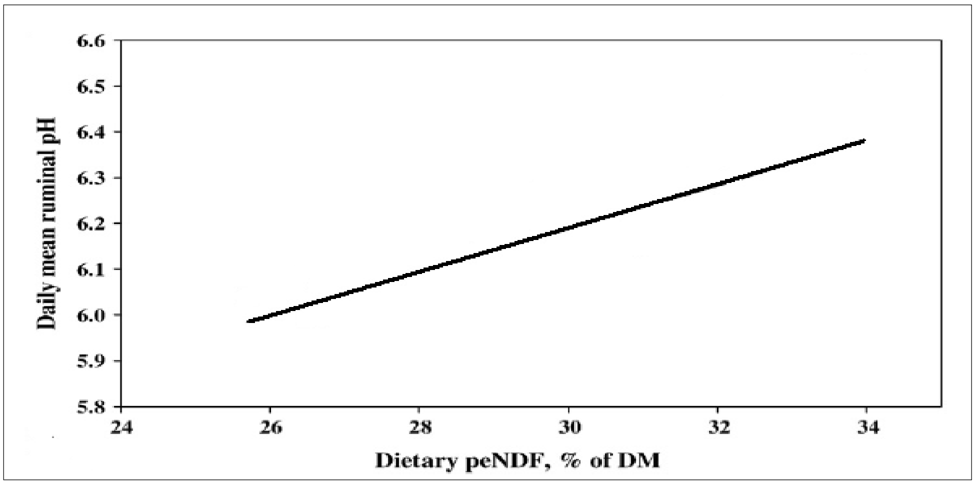

Fig 3: Effects of dietary peNDFN on daily mean ruminal pH in high-producing dairy cows (Zebeli *et al*., 2010) [22]

3.3 Effect on feed intake

Regulation of Feed intake depends on the meal size and the meal frequency and these two variables are in turn affected by the PS, concentrate size and forage source (Zebelia *et al*., 2010, Mazzenga *et al*., 2009) [22]. High producing dairy cattle require a high feed intake in order to maintain the milk production and their productivity. Enhanced ease of NDF hydrolysis may stimulate rapid turnover of NDF from the rumen and allow greater voluntary feed intake (Allen and Oba, 1996; Tafaj *et al*., 2005) [17].

The effects of dietary PS or peNDF on DMI in high producing dairy cows are often controversially discussed. Because of the positive effects on physical fill, and low peNDF content in the diet is believed to increase feed intake in dairy cows. Tafaj *et al*., (2005) [17] by combining the different individual studies reported that, the effect of dietary PS on DMI may depend on forage source, forage to concentrate ratio and on the type of concentrate, which has significant effect on the ruminal degradation rate reflecting their effects on rumen conditions and digestion.

3.4 Effect on milk fat production

PeNDF plays a major role in maintaining proper ruminal ecosystem and promoting the efficiency of microbial fermentation. Feeding diets excessive in peNDF than the requirement may also adversely affect milk production and feed efficiency (Yang and Beauchemin, 2006b). Milk fat yield is directly related to rumen fermentation products and function, milk fat content is often used as an indicator of rumen health and fibre adequacy in dairy cows. Using approach of PSPS, the requirement for peNDF of dairy cows was determined to be 20% of ration DM to maintain the milk fat percentage of early to mid-lactation Holstein cows at 3.4%.

The mechanism that explains milk fat depression syndrome in high producing lactating ruminants involves dietary fibre intake, chewing activity, salivation, and ruminal fermentation. A high-fibre diet results in higher chewing activity, which in turn increases salivation and favors the growth of cellulolytic microbes and production of acetic acid. Higher acetate to propionate ratio in the rumen liquor favors the synthesis of milk fat, since acetate is the major precursor of milk fat (Aghsaghali *et al*., 2011) [12].

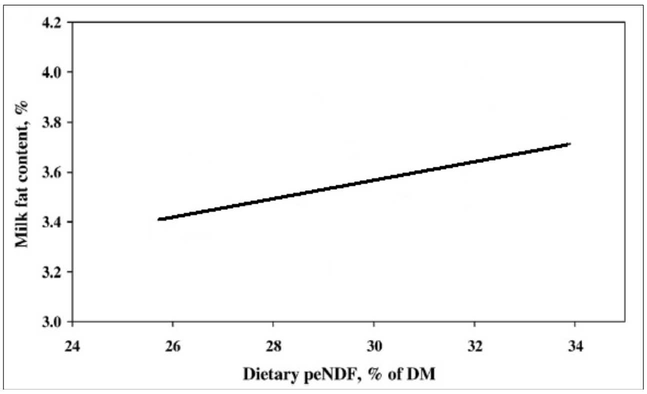

Fig 4: Effects of dietary peNDF on daily milk fat content in high-producing dairy cows (Zebeli *et al*., 2010) [22]

Mertens (1997) [11] described the series of events when less peNDF is fed in dairy cows that include decreased chewing activity, less salivary buffer secretion, lower ruminal pH, altered ruminal fermentation patterns and the low ratios of acetate-to-propionate in the rumen that ultimately result in modified animal metabolism and reduced milk fat synthesis. Zebelia *et al*., (2006) [21] conducted a regression analysis and found that milk fat content in dairy cows positively correlates to chewing activity. According to this analysis, dairy cows must consume a sufficient amount of peNDF to achieve a chewing time of 687 min/d or30 min/kg DM ingested in order to produce milk having 3.4% of fat.

Particle size and effective fibre recommendations

The National Research Council recommends NDF to be maintained at 25% of dietary DM with at least 75% from forage for the NDF requirement. Till now no recommendations are given for the physically effective fibre due to lack of standards and validated technique to quantify the physically effective properties of fibre in the diet. The most current reliable method to assess effective fiber may be to evaluate fiber levels and particle size distributions individually. Using approach of PSPS, the requirement for peNDF of dairy cows was determined to be 22% of ration DM to maintain an average ruminal pH of 6.0.

When evaluating a TMR, the proportion of material retained on the top screen, or greater than or equal to 19.0-mm is often considered. This is because the intake of DM from this portion of the diet is known to be positively correlated with ruminating activity and has been demonstrated to be negatively correlated when time rumen pH is below 5.8 (Kononoff *et al*., 2003b) [8].

Future perspectives

More research works should be conducted for the nutrient recommendations of dairy cattle at different physiological, in terms of particle size and physically effective fibre. More studies are required to understand the interaction between the different components of the ration, in order to formulate a balanced ration. There is a need to improve the practical understanding of forage particle size or physically effective fibre on feeding activity and behavior.

Conclusion

Physical characteristics of dairy rations are very critical for obtaining proper ruminal fermentation. Ruminants require fibre in coarse physical form, which has a significant effect over chewing and ruminal activity. Effective fiber is that portion of a dairy diet that stimulates chewing activity, salivary buffer production and increased rumen pH. Physically effective NDF has been proposed to estimate effective fiber and is the portion of NDF in the diet that stimulates chewing activity and possibly forming the rumen mat. Several methods to measure peNDF have been proposed with each at differing stages of development and validation.

The peNDF content of an individual feed is calculated as the product of the NDF concentration and the physically effectiveness factor. PSPS is commonly and routinely used separator to express the particle size distribution, and to calculate the content of peNDF. Till now no recommendations are given for the physically effective fibre due to lack of standards and validated technique to quantify the physically effective properties of fibre in the diet.

Reducing forage particle size may reduce the effective fiber levels in dairy diets but increase DMI, digestibility and concentrations of rumen total VFAs. Reducing feed particle size within recommended ranges also may reduce the feed bunk sorting behavior of dairy cattle and increase fiber intake. Although chewing activity is closely related to particle size, it may have moderate effects on rumen pH (a function of increased salivary flow). Other factors such as the amount of fermentable carbohydrates may be more critical when ration NDF levels are near recommended levels.

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