FEEDING DAIRY COWS

3. FORAGE PARTICLE SIZE AND EFFECTIVE FIBRE

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INTRODUCTION

Forage is an essential ingredient in dairy cattle feed. Its inclusion in the diet is necessary to ensure proper digestive function and achieve maximum productive potential without harming the animal's health and well-being.

However, forage has a limited energy content and a high fibre content, so only the minimum proportion necessary should be included in the ration administeres to high production cows. When using forage in a TMR, it must be chopped to reduce particle size in order to increase intake and digestibility and improve mixing with other ingredients in the ration.

However, the resulting particle size can modify the effect of dietary forage; both excessive and defective chopping may negatively affect the animal's health and productive performance.

Here, we analyse the effect of chopped forage particle size on intake, digestibility and milk production and composition, examine the difference between fibre and effective fibre and discuss current recommendations for dairy cattle regarding the content of effective fibre in the ration.

DOES THE SIZE OF CHOPPED FORAGE INFLUENCE INTAKE, DIGESTIBILITY AND MILK PRODUCTION AND COMPOSITION?

The answer to this question is yes, in general terms. However, the results of scientific research are variable because among other factors they depend on the type, amount and size of the chopped forage compared with the rest of ingredients in the ration.

A reduction in forage particle size decreases rumination time as well as the number of mastications during intake and rumination. This enhances intake because it reduces the satiating effect associated with the number of mastications, and it increases the rate of passage of feed through the digestive tract.

FIGURE 1
As particle size decreases, chewing, ruminating activity and saliva production are reduced, and feed intake and passage rate increase.

As shown in Figure 2, there is a direct relationship between the size of chopped forage and intake, saliva production, the number of mastications and rumination time, results which have been confirmed by Teimuri Yansari et al. (2004) and Beauchemin and Yang (2005).

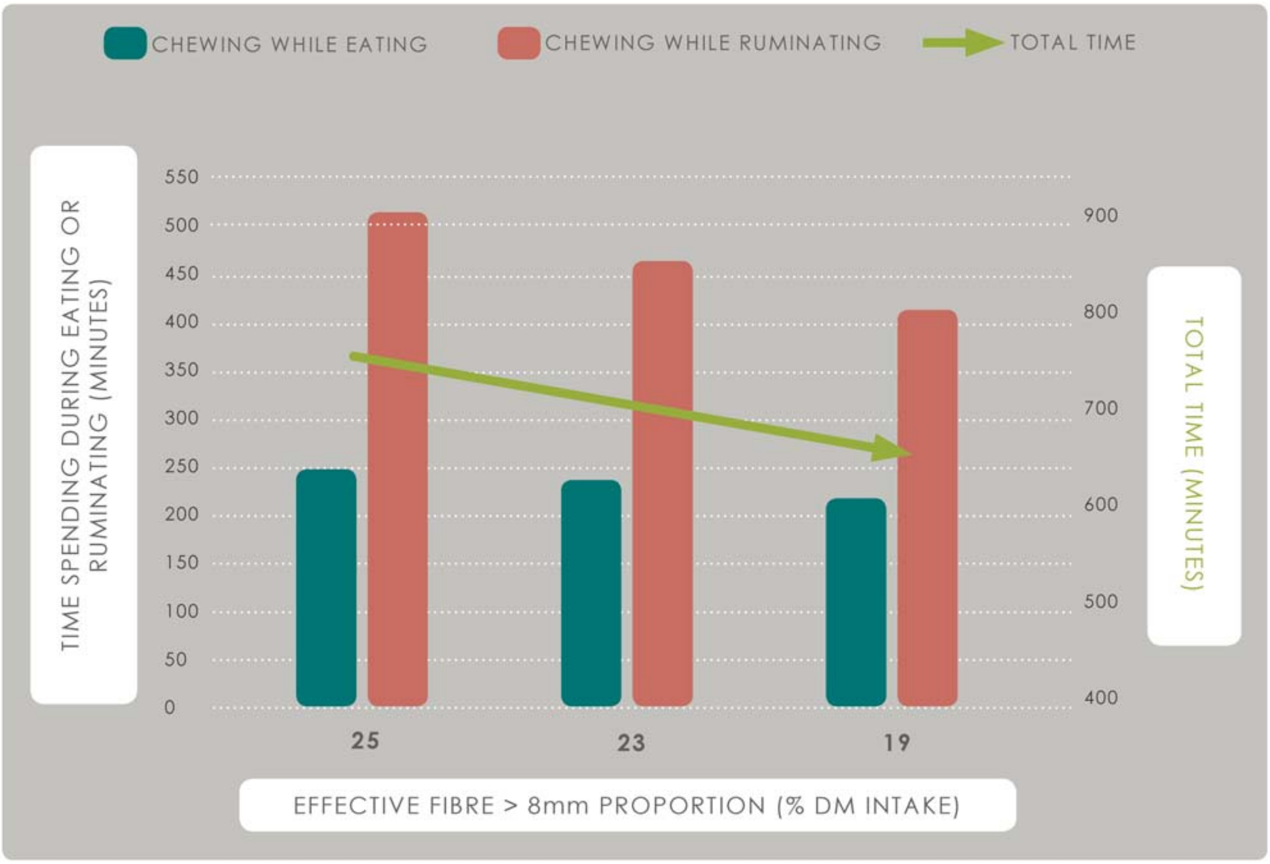

FIGURE 2
Reduction of effective fibre proportion lessen the time spent by animals in chewing during eating and rumia, and total time. Own elaboration based on the data from Yang & Beauchemin (2006).

Most authors agree that as feed particle size is reduced, the surface area accessible to rumen microorganisms increases and therefore the rate of digestion rises, increasing digestibility. However, if the particle size is very small, the increased rate of feed passing through the digestive tract means that the particles spend less time in the rumen, counteracting the increased rate of digestion and sometimes reducing digestibility. The smallest particles remain less time in the rumen and are therefore available to rumen microorganisms for less time, thus decreasing digestibility, particularly that of fibre (Yang & Beauchemin, 2005) (Figure 3).

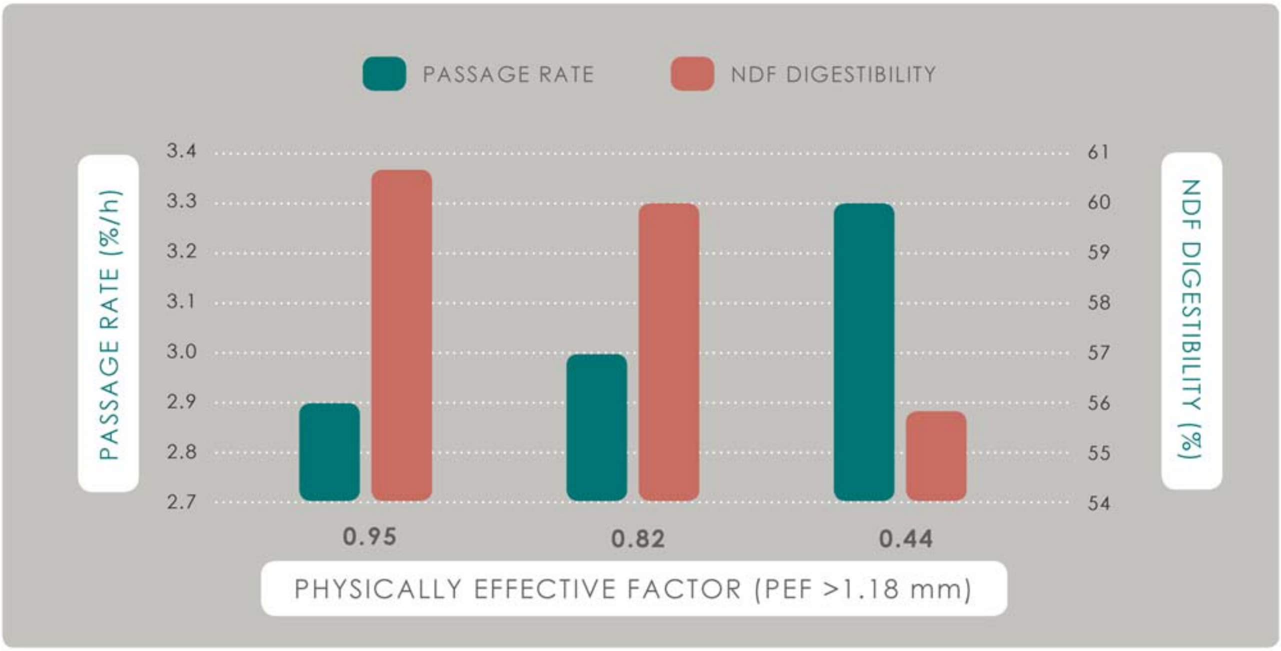

FIGURE 3
Effect of particle size on passage rate and NDF digestibility. Own elaboration based on the data from Teimuri Yansari et al. (2004).

An excessively small particle size has also been associated with a reduction in rumen pH and the ratio of acetate to propionate. Under normal conditions, rumen pH is between 6.2 and 7 and is the result of a balance between the acids produced during fermentation of the feed in the rumen and pH buffer systems. The large amount of saliva produced during rumination contains bicarbonates and phosphates that neutralise the acids (lactate and volatile fatty acids) generated by fermentation of carbohydrates (e.g. cellulose, hemicellulose, starch).

Rumination and therefore saliva production is stimulated when the animal eats feed with a high fibre content (crude fibre or neutral detergent fibre), such as forage. Conversely, when the animal ingests concentrated feed with a high content of easily fermentable carbohydrates such as starch, rumination and saliva production decreases and acid production increases, reducing rumen pH. In addition, if forage is too finely chopped, the fibre will not stimulate rumination or saliva production effectively, which can cause acidosis (pH below 6.2).

A reduced pH can exert different effects, such as a reduction in milk fat content. Thus, for example, Grant et al. (1990) administered diets containing alfalfa silage with 3 different particle sizes (thick: 3.1 cm, fine: 2.0 cm, and an intermediate size obtained from a mixture of both sizes) and found no differences in intake or milk production but did detect a difference in milk fat content, which was attributed to a drop in rumen pH when animals were fed diets with finely chopped alfalfa. A reduction in rumen pH alters the production of acetic acid (precursor of milk fat) and modifies fatty acid biohydrogenation, generating intermediate products that can reduce fat synthesis (Yang et al., 2001; Shingfiel et al., 2010).

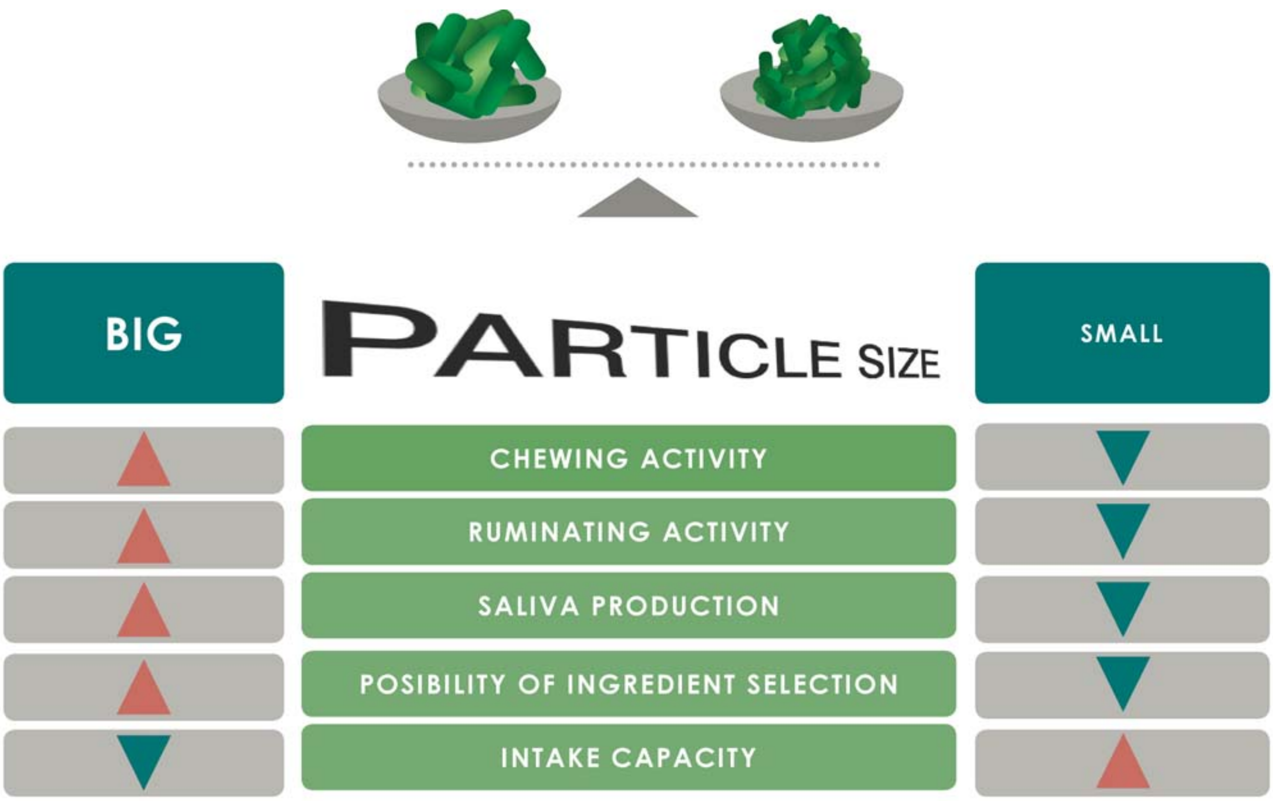

FIGURE 4
A small or large particle size affects the chewing activity, saliva production and feed intake.

In summary, particle size has the potential to affect feed intake and digestibility and milk production in dairy cows, but its effects depend on the type, amount and storage of the forage employed (Narollahi et al., 2015). It is therefore necessary to determine optimal particle size to reap the benefits while avoiding any harmful effects caused by excessively large or small sizes. Thus, when formulating dairy cattle rations it is necessary to pay attention not only to fibre content but also to feed particle size, if the fibre is to be really effective.

WHAT IS EFFECTIVE FIBRE?

The concept of effective fibre arose from the need to establish the minimum amount of fibre necessary to maintain an adequate milk fat content. The concept of physically effective fibre (peNDF) was formulated by Mertens (1997), and consists of the minimum forage particle size required to stimulate saliva secretion, maintain pH above 6, support the biphasic nature of rumen content (NRC, 2001), and promote proper digestion of fibre (Yang et al., 2002).

Theoretically, any feed fibre that does not negatively affect milk fat content would be as effective as forage fibre. In practice, however, the neutral detergent fibre (NDF) present in concentrated fooders, primarily composed of cereal grains, is less effective because of its smaller particle size. Consequently, it does not provide the physical texture of forage necessary to maintain appropriate rumen conditions or milk production levels.

The term peFND thus refers both to chemical composition and ration particle size distribution.

HOW IS EFFECTIVE FIBRE MEASURED?

At present, there are several methods available on the market for quantitatively determining particle size distribution in the rations fed to livestock. These basically consist of a series of stacked sieves with a decreasing mesh size; the ration is placed in the upper sieve and the particles are then separated out into different levels according to their size and the procedure established for their use. These methods can be classified as wet or dry.

Wet methods use water to move the sample from one sieve to the next, and graphically simulate the flow of completely saturated feed particles through the omasal canal. Dry methods do not use water and separation is achieved through horizontal and even vertical vibration and agitation of sieves with different mesh sizes.

The quantity of feed retained in each of the sieves is used to obtain the physical effectiveness factor (pef), calculated as the proportion of particles retained in the different sieves or groups of sieves, and the peNDF, calculated as the product of the percentage of NDF in the feed and the pef. Most authors calculate effective fibre as the amount of feed that passes through an 8 mm sieve and is larger than 1.18 mm.

WHAT IS THE PENNSYLVANIA SEPARATION METHOD?

Of the various methods and tools on the market, the most widely used is the Pennsylvania State TMR and forage particle separator known as the Penn State Particle Separator (PSPS) (Figure 5), designed following research conducted by various authors (Lammers et al., 1996). Used to separate TMR and forage particles, the method initially consisted of 2 sieves with a mesh size of 19 and 8 mm and a blind box at the bottom to collect smaller feed particles. The ration is placed in the upper sieve and the particles are separated out into two levels according to their size.

Based on research conducted by Kononoff et al. (2003), a third sieve was incorporated into the PSPS with a mesh size of 1.18 mm since this is the critical size for particle retention in the rumen in cattle and sheep (Poppi et al., 1980, 1981). Particles smaller than 1.18 mm do not stimulate rumination or maintain appropriate conditions (Mertens et al., 1986), and are flushed out from the rumen during the liquid phase, which leaves the rumen faster. Addition of the 1.18 mm sieve yields a more precise description of sample fineness and average particle length. Recently, a fourth 4 mm sieve has been incorporated into the PSPS (Heinrichs, 2013).

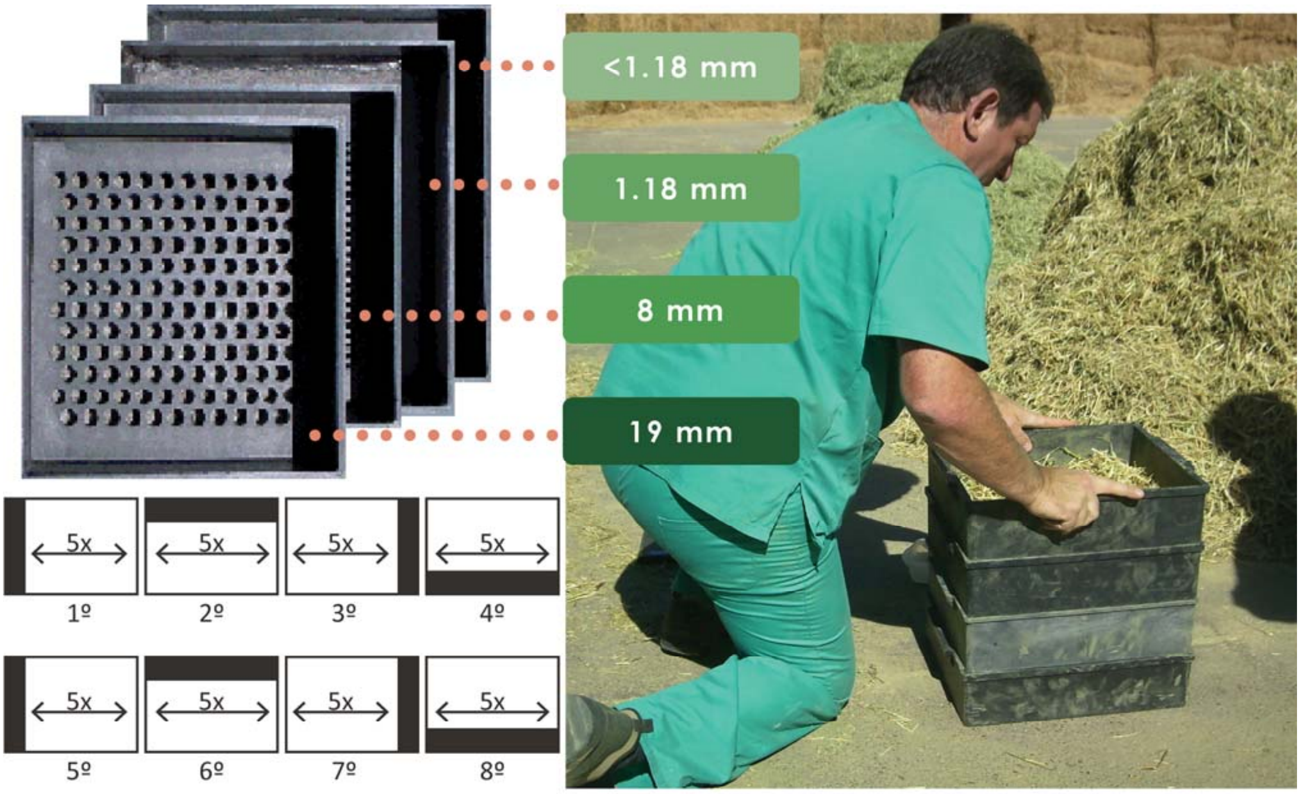

FIGURE 5
PSPS, Pennsylvania State University forage Particle Separator, 3 sieve model, and sieve shacking pattern.

WHY ARE 19, 8, 4 AND 1.18 mm SIEVES USED?

Sieve sizes were selected in accordance with rumen stratification (Figure 5). The first size (19 mm) corresponds to a particle size that stimulates rumination and saliva, and thus maintains optimal rumen pH. The next size (8 mm) mainly collects feed particles that form part of the solid phase in the rumen and require a period of rumination and hydration for microbial degradation to occur, the length of which will depend on the digestibility of this fraction. Typically, the 4 mm fraction would consist of fibrous or non-fibrous feed particles that are initially be trapped in the solid phase of the rumen and are quite easily hydrated, but which are rapidly degraded in a short rumination time by microbial action, and have no significant impact on buffer capacity in the rumen.

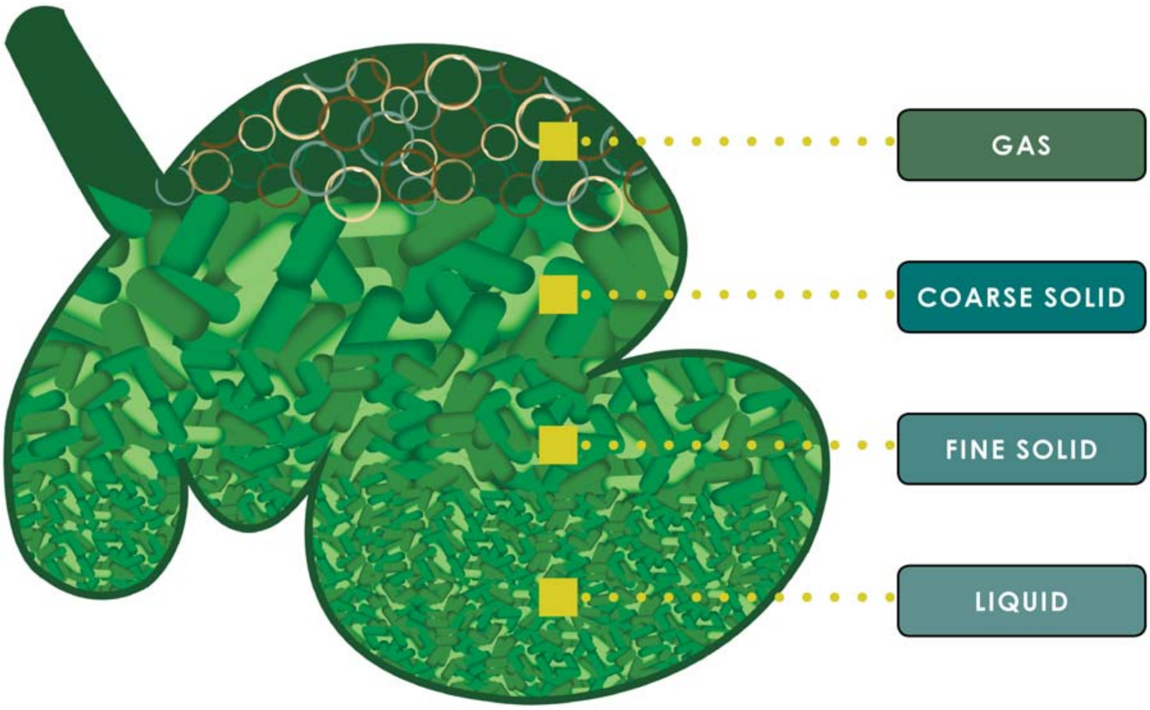

FIGURE 6
Feed particles during digestion, and fermentation products arrange in 4 different layers in the rumen.

The fourth, 1.18 mm sieve usually retains cereals and easily degradable carbohydrate components which leave the rumen in the soluble fraction and are taken as the reference for estimating maintenance levels of peFND for both sheep and cattle.

WHAT IS THE OPTIMAL PERCENTAGE OF EFFECTIVE FIBRE IN THE RATION?

Zebeli et al. (2010a) used mathematical models to study dairy cow response to the chemical and physiological characteristics of their diet in order to optimise diets and provide the requisite effective fibre, expressed as the % of peFND > 8 mm ($peFND_{>8\ mm}$). Using data from 64 studies and 257 different diets, they concluded that an 8 mm particle size was the threshold to maintain appropriate physiological conditions of rumen pH, rumen activity and fibre digestion.

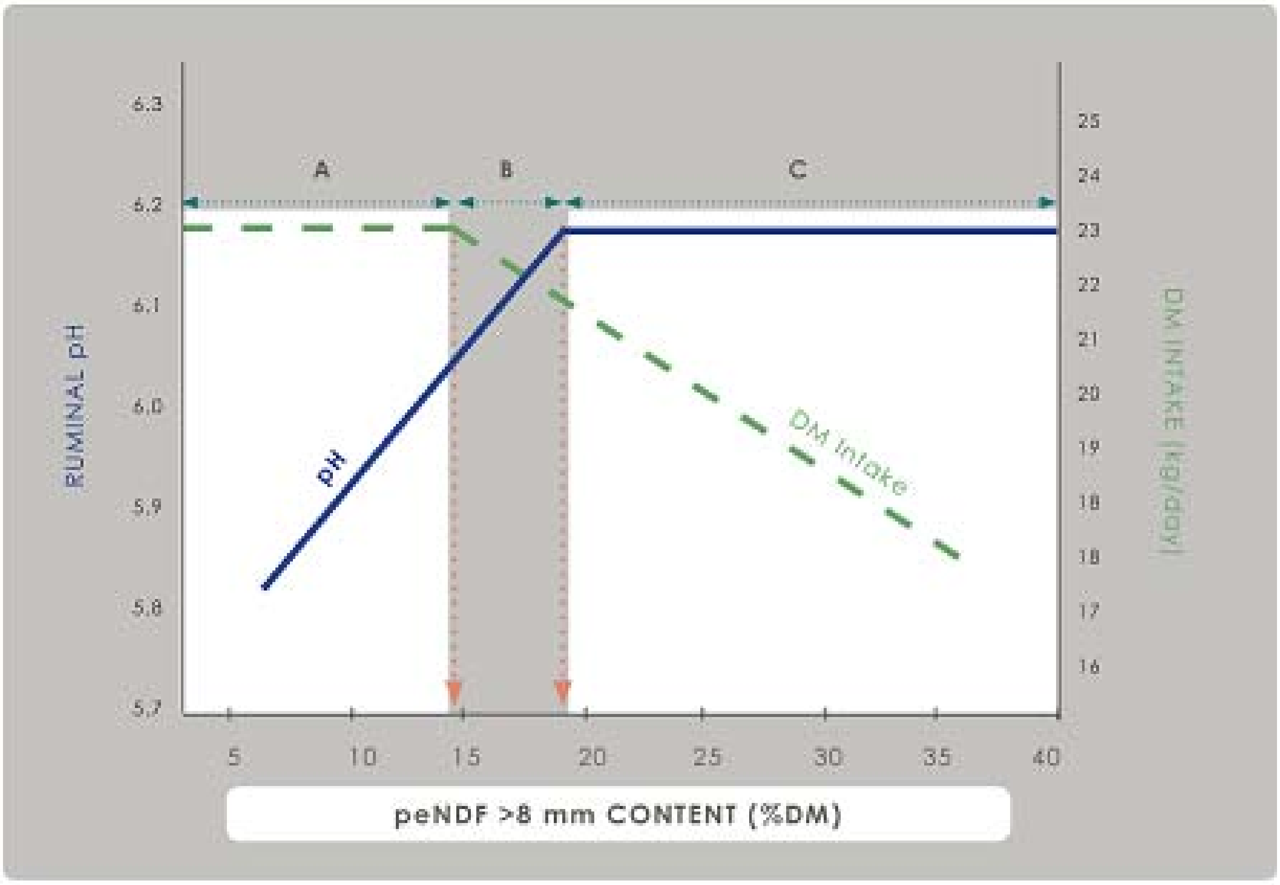

FIGURE 7
Relationship between peNDF >8mm content and dry matter intake (green line) or ruminal pH (blue). A) Typical diet of high producing cows in the stage in the early lactation, with high demand for nutrients and energy and at risk of acidosis. (B) Acidosis safe area, although deficient in intake as peNDF>8mm in the ration increases. C) Typical area of diets for high producing lactating cows in the middle and late stages of lactation. Source: by the authors, based on data from Zebeli et al. (2010a, 2012).

The results of this study (Figure 8) indicate that for high production cows in the middle and late stages of lactation, the minimum $peFND_{>8mm}$ content must be between 17 and 18.5% in order to maintain rumen pH and a relatively high DM intake. In the early stage of lactation (< 16 weeks), the % of $peFND_{>8mm}$ must be between 14 and 15%.

Zebeli et al. (2010b) also recommended a $peFND_{>1.18mm}$ content of 30-32% to maintain pH above 6.2 and avoid the risk of acidosis and a reduction in milk fat without having a detrimental effect on intake or milk production. In addition, they suggested that diets containing a ratio of $peFND_{>1.18mm}$ to degradable starch in the rumen below 1:45 should be avoided. Meanwhile, Mertens (1997) recommended a physically effective fibre content ($peFND_{>1.18mm}$) of 19.7% of the ration to maintain 3.4% milk fat, and a $peFND_{>1.18\,mm}$ of 30% to maintain rumen pH above 6.

The method designed by the University of Pennsylvania to determine the percentage of effective fibre has proved extremely useful on farms and has become an international benchmark for determining feed particle distribution due to its ease of use, cleanliness, low cost and speed. Nevertheless, the range of sizes that can be measured is limited, and although it presents acceptable repeatability, the separator requires manual operation which can lead to error if the operating procedure varies in terms of agitation intensity, speed and individual differences (Kononoff et al., 2003).

Furthermore, the concept of effective fibre does not take differences between diets into account, such as the forage to concentrate ratio, the form in which cereals are presented, or cereal starch fermentability of the elements that comprise the ration (e.g. soluble fibre content). It is therefore difficult to establish practical recommendations of a general nature; rather, recommendations should be based on experience acquired under specific conditions.

A clear example of this is the different behaviour of forage when chopped during TMR preparation, depending on the type of forage used. For example, after chopping dehydrated alfalfa for 3 min in a TMR mixer-wagon, 10% of the fibre is less than 1.18 mm and around 25% will range between 1.18 and 8 mm. However, in the case of alfalfa hay, 3 min of chopping will barely reduce particle size; being about 4% lesses than 1.18mm, and 14% range between 1.18 and 8 mm. In other words, over 80% of the fibre is larger than 8 mm (see Figure 8).

In the case of dehydrated alfalfa, 3 min is sufficient to obtain a correct particle size distribution, obtaining a homogeneous mixture that does not limit intake and provides a sufficient percentage of effective fibre However, in the case of alfalfa hay, a longer chopping time is required because of the very high percentage of particles that remain larger than 8 mm, reducing intake and hindering the preparation of a homogeneous TMR.

FIGURE 8
Dehydrated alfalfa requires less processing time in the TMR wagon than alfalfa hay in order to attain suitable forage size. Source: by the authors, based on own data.

Consequently, 3 min chopping is sufficient in the case of dehydrated alfalfa, whereas hay requires a longer chopping time, thus consuming more labour and energy (mixer-wagon operating time).

FIGURA 9
Dehydrated alfalfa requires less chopping time and thus the TMR ration faster takes less times to prepare.

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