FORAGE PARTICLE SIZE: IT’S IMPLICATIONS ON BEHAVIOR, PERFORMANCE, HEALTH AND WELFARE OF DAIRY COWS

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ABSTRACT: Forage particle size has long been recognized as the key intricate factor determining ration contents of physically effective neutral detergent fibre, which in recent years has become the most important consideration in advanced dairy feed formulation for the rumen health, milk yield and welfare of the dairy cows. Fine chopping reduces particle size, resulting in reduced forage dry matter intake, lower retention period of digesta, decreased digestibility of fiber, inconsistent quality of ruminal mat, decreased milk yield, depression of milk fat, and health issues secondary to sub-acute ruminal acidosis. Similarly, excessive coarse forage may lead to reduced total nutrient intake, poor digestibility of organic matter, reduced milk yield and quality, and compromised overall performance. The rumen is a constant fermentation vessel, containing vast amounts of hydrogen ions that can only be stabilized by a proper salivar buffer balance obtained through intake of sufficient effective neutral detergent fibre and its optimal duration. The overall impacts of particle size, however, depend on forage type, forage to concentrate ratio and, fermentability characteristics of the organic matter in the formulated ration. In general, 8-19 mm particle size irrespective of forage type measured on Penn State Particle Separator may be considered optimum for practical dairy feed formulation.

Keywords: Dairy cattle, Forage particle size, Health, Milk yield, Performance.

INTRODUCTION

Forage particle size (FPS) or chop length (CL) has long been recognized as one of the principal factors influencing feed intake (Haselmann et al., 2019), feed sorting behavior (Jiang et al., 2018), digestibility of feed (Zhao et al., 2020), rumination (Deswyssen et al., 1978), turnover kinetics of rumen metabolites (Storm and Kristensen, 2010), rumen pH (Kmicikewycz and Heinrichs, 2015), microbial protein synthesis (Rodriguez-Prado et al., 2004), milk yield (Havelkes et al., 2020), milk fat content (Sharifi et al., 2012), profile of milk fatty acid (Thomson et al., 2017), milk protein percent (Nasrollahi et al., 2015) and overall, cow health (Havelkes et al., 2020). The ruminant diet is dominant in crude fibre which is inevitable for their health, productivity and welfare. The rumen appears to be a continuous fermentation vat that produces large quantities of hydrogen ions (60,000 mEq/day or more) (Allen, 1997). Thus, upkeep of stable ruminal pH is intricate. The ruminal pH is in equilibrium by two key factors: an appropriate balance of slowly and rapidly fermentable carbohydrates and adequate physical fiber to stimulate chewing activity and saliva production (Allen, 1997). Fine chopping reduces FPS and thus can decreases the physically effective neutral detergent fibre (peNDF) contents of diet (Stojanović et al., 2013). The peNDF contents of diet, thus, virtually results from the interaction between the contents of chemical fiber and forage chop size in the diet (Gümüş and Bayram, 2020). The shorter than the optimum FPS may result in low dry-matter intake, decreased fiber digestibility, decreased milk yield, milk fat depression, and health problems secondary to sub-acute ruminal acidosis. Similarly higher than recommended FPS may provoke feed sorting, spending excessive time for re-chewing, higher retention time of digesta and reduced fractional passage kinetics of particulates. This review, therefore, aims to highlight the link between FPS and peNDF contents of the rations and their subsequent buffering implications on production, health, efficiency of nutrient utilization, and welfare of the dairy animals and explains why not too long, not too short, but “just right” FPS is required for dairy cows.

BEHAVIOR

Feed sorting

Twenty Holstein bull calves were exposed in the total mixed rations to observe the effect of early introduction to rations varying in FPS on the progression of feed sorting in dairy calves (Miller-Cushon et al., 2013). Calves offered the low FPS diet consumed less neutral detergent fiber as a level of anticipated intakes and would in general consumed less acid detergent fiber and more non-fiber sugars, than the calves recently fed the high FPS diet. It showed that calves recently fed the low FPS diet were sorting for concentrate and this sorting behavior might have been influenced by their early involvement in the rations varying in FPS. Similarly, twelve multiparous lactating Holstein dairy animals were exposed in a
replicated 4 × 4 Latin square design with a 2 × 2 factorial arrangement to decide the impacts of FPS on feed sorting behavior. As a rule, sorting activity decreased with reduced forage particle size. In any case, the dairy animals fed high quality forage had a lower sorting activity and higher production performance than those who fed low-quality forage (Jiang et al., 2018). In another study, larger FPS forages increased sorting behavior (Figure 1); however, had no impact on rumen fermentation or chewing behavior of the animal (Suarez-Mena et al., 2013). In another experiment (Leonardi et al., 2005), the consequences for feed sorting of various amounts, characteristics, and lengths of alfalfa feed were tried, without changing the extent of concentrate in the eating regimens. These investigators found that the dairy animals increased their sorting activity with more hay and with longer hay, though the quality of feed had no impact. Similar impacts of particle size have been demonstrated by other investigators (Kononoff and Heinrichs, 2003).

Despite the fact that few scientists have indicated that sorting against long particles and NDF can be decreased by changing the quality of forages inside a TMR (Kononoff and Heinrichs, 2003) nobody has clearly explained how do the extent of forage in the eating regimen impacts sorting behavior. It was demonstrated that animals effectively opposed long particles, NDF, and peNDF, and chose for short particles when taken care of a long forage diet. This finding negates the speculation that animals would sort more with increased forage in the eating regimens. It was accepted that animals would be exceptionally energetic to sort for the concentrate part of their TMR, particularly when accessibility of concentrate was restricted. Accordingly, it was accepted that decreasing the concentrate divided in the TMR would propel dairy cows to sort for the concentrate and against forage (Voelker et al., 2002). The increased sorting of the long forage diet demonstrated, in any case, that a ration with higher extent of concentrate might be all the more effectively sorted, essentially in light of the fact that the concentrate content is progressively available than the roughages.

![Figure 1 - Effects of forage particle size on feed sorting in dairy cows (Maulfair et al., 2010). The TMR contains short (1.5 mm), medium (6.5 mm), long (8.6 mm), and extra-long (11.7% 26.9 mm) particles.](image)

**Chewing and rumination**

Forage size affects both eating and chewing time (Table 1; Figure 2). Rumination time decreased from 504 to 400 min/d for cows expending short particle size contrasted with long particle size. Similarly, chewing was decreased from 702 to 570 min/d when dairy animals consumed short particle size (Ramirez Ramirez et al., 2016). In a different study, forty-eight Holstein calves were arbitrarily distributed in a 2 × 2 factorial plan to examine the impacts of FPS on sorting behavior of dairy calves fed texturized concentrates (Omidi-Mirzaei et al., 2018). Calves fed forage with long FPS invested more energy for rumination, eating forage, and invested less time lying and non-nutritive oral practices than medium particle size. Essentially, the cows decreased eating and ruminating time by 4.8 and 1.9 min, respectively per kilogram of DMI and demonstrated lower rumination endeavors while fed low FPS diet (Haselmann et al., 2019). Thus, increased chewing and rumination because of elevated FPS is predictable.

| Table 1 - Influence of forage physical form on chewing activity |
|---------------------------------------------------------------|
| **Item** | **Form of hay** | **Long** | **Chopped** | **Pelleted** |
|----------|-----------------|----------|-----------|-------------|
| Eating, min/d | | 196<sup>a</sup> | 174<sup>a</sup> | 128<sup>b</sup> |
| **Ruminating** | | | | |
| min/d | 383<sup>a</sup> | 398<sup>a</sup> | 61<sup>b</sup> |
| min/kg NDF intake | 64.1<sup>a</sup> | 64.4<sup>a</sup> | 10.2<sup>b</sup> |
| **Total chewing** | | 579<sup>a</sup> | 572<sup>a</sup> | 189<sup>b</sup> |
| min/kg DM intake | 29.2<sup>a</sup> | 28.6<sup>a</sup> | 9.8<sup>b</sup> |

**Means in the same row within measures with different superscripts differ (P<0.001).**

![Citation](image)
**Ruminal mat consistency**

Particle size legitimately influences the rumen mat, which is shaped by little particles holding adherence of the longer-stem forages that float in the rumen. This connection permits the smaller particles to stay suspended in the rumen to be appropriately fermented. Without adequate fiber, particles may sink into the less-desirable sites of the rumen where they cannot be digested properly. Thus, the benefits of high FPS is likely for better mat consistency.

**Retention time of digesta**

Rumen fill can physically constrain the retention time of digesta in dairy cows in forage-based eating regimens with high FPS (Shaver et al., 1988). Feed residues normally do not get away from the rumen either by a decrease or by the restricted entry of additional intake. In spite of the fact that the impacts of the rate of particle size decrease on ruminal retention time is not consistent, nevertheless, it was recommended that the rumen comprises of a ruminating pool of larger particles that cannot go through the reticulo-omasal orifice until arrive at a smaller particle size (Ternouth, 1968). In light of this rate restricting particle size decrease hypothesis for particulate passage, it was recommended that the higher FPS will lengthen retention time (Figure 3 and 4) and the other way around (Poppi et al., 1980). Detailed information is minimal about the distribution of particle size at different locations within the reticulo-rumen, abomasum and intestines. However, coarse particles were more abundant in the dorsal than ventral rumen, which decreased with time after eating, it was observed (Evans et al., 1973). This variable distribution of the small particle pool coupled with small variations in high and low FPS chewing behavior may raise the question as to the role of reducing particle size in the rumen particle passage. For low and high fiber forages, the large proportion of small particles in the lumen suggests that the rate of escape of small particles from the rumen is an important factor determining the retention time of the rumen. In relation to the longer retention time of the large particle itself, the effect that larger particles have greater retention time in the rumen may be due to their effect on the forming of the rumen mat and eventual trapping of small particles (Shaver et al., 1988).
**PERFORMANCE**

**Dry matter intake**
Overall, type and nature of the feed, body condition score, health, sex, age, equality of animal, milk yield, milk composition, environmental temperature, and humidity are the most dependable indicators influencing dry matter intake (DMI; Table 1) in dairy animals (Méndez et al., 2020). Explicit impacts of FPS on DMI are scant. The impact of FPS on DMI in dairy animals was assessed utilizing a meta-analysis with 46 papers and 28-91 preliminaries of published information from the literature (1998-2014). It was obvious that DMI improved because of bringing down the impact of FPS containing silage however not hay (Nasrollahi et al., 2015). In another study, the peNDF substance of dairy cattle diets was changed by differing levels of FPS of alfalfa silage (Li et al., 2020). Expanding peNDF substance of diets by expanding FPS decreased DMI. Therefore, the expansion in DMI because of decreased FPS was noteworthy in animals taken care of wild-rye feed diets (Jiang et al., 2018). In another study, the effects of physical form and stage of maturity at harvest of whole-crop barley silage on feed intake in dairy steers were evaluated in a 4 × 4 Latin square design (Rustas et al., 2010). It was assumed that, chopping increased DMI when grain was collected at the dough stage however not at the peak phase of maturity (Rustas et al., 2010). Decreasing the corn silage chop length increased dry matter intake ranging 22.3-23.2 kg/d, at 4 to 5 h in the wake of intake or milk production (Bhandari et al., 2008). The decrease in FPS increased DM consumption from 19.4 to 20.1 kg/d at the elevated level of concentrate and from 16.9 to 17.7 kg/d at the low degree of concentrate (Einanon et al., 2004).

Despite the fact that, sorting practices because of inconsistencies in FPS typically hinder the eating rate, yet again inverse evidence was demonstrated (Devries et al., 2007). It was accounted for that, dairy animals consuming the long forage diet consumed at a more prominent rate and in a shorter time span. Johnson and Combs (1992) additionally found that cows consuming a half forage diet invested less energy eating than those fed a 74% forage diet. Conversely, Voelker et al. (2002) revealed comparable intake times for cows fed a 67 or 44% forage diet. These last researchers proposed that such inconsistencies in intake times might be the aftermath of contrasts in dietary particle size. However, neither of these past studies revealed dietary particle size. Strikingly, Voelker et al. (2002) reported that the eating time per kilogram of DMI was lesser for the animals taken care of a 44% forage diet, showing that these dairy animals consumed their DM quicker, like the more noteworthy intake rates on the long forage diet found in the current study. Allen (2000) expressed that the dietary factors that expansion eating time could decrease the time accessible for ruminating, in this way expanding the filling impact of the diet. Similarly, in this study, the high forage diet spent more time to be consumed, likely due to its high NDF substance and longer particle size. These variables may have added to an increased filling impact, representing the lower DMI on the high forage diet. Johnson and Combs (1992) noticed DMI as lower on their higher forage diets.

**Forage degradability**
Digestibility of dry matter or organic matter is improved when long forage particles are chopped but not ground (Tables 2 and 3). The impacts of FPS on degradability of individual amino acid (AA) in the digestive tract of lactating dairy cows with ruminal and duodenal cannulas were estimated in a Latin square design (Zhao et al., 2020). Degradaibility of most individual AA in the rumen was not influenced by FPS. In another study, the low FPS diet altogether increased total tract digestibility of the supplements (Haselmann et al., 2019). Chopping the dough stage silage decreased the extent of grain in defecation from 97 to 43 g/kg DM demonstrating higher starch digestibility (Rustas et al., 2010). However, expanding FPS had no impact on AA supply however the digestibility of individual AA in the digestive tract changed significantly (Li et al., 2012). Total tract absorption of dietary NDF was decreased for fine-handled corn silage contrasted and control corn silage and coarse-prepared corn silage (28.4% versus 33.9 and 33.7%, respectively). Processing corn silage improved starch digestibility (Bal et al., 2000). It was accounted for that changing the forage particle size from 6 to 30 mm in a low-concentrate diet substantially increased the rumination time and ruminal mat consistency without influencing ruminal fermentation and passage. Further, particle breakdown and consistency of mat in the rumen increased, and in situ feed dry matter degradability improved, which thus demonstrated a higher capacity of ruminal digesta to degrade fiber (Zebeli et al., 2008).

**Fractional passage kinetics**
Long particle size feeding lowered the rate of dry matter passage from 3.38 to 2.89±0.42 percent/h; mean retention time rose concomitantly from 31.7 to 38.4±5.36h for long particle size diets (Ramirez Ramirez et al., 2016).

**Feed efficiency**
Twelve multiparous lactating Holstein animals were exposed in a replicated 4 × 4 Latin square design with a 2 × 2 factorial arrangement to decide the impacts of forage source and size of particle size on feed sorting, milk production and supplement digestibility in lactating dairy cows. The experiment featured that, feed efficiency (4% fat-adjusted milk/DMI) improved from 1.18 to 1.11 when FPS decreased independent of forage source (Jiang et al., 2018).

**Milk yield**
An increased DMI is associated with increased milk yield (Table 5). Thus, increasing peNDF content of diets by increasing F:C ratio may decrease milk yield due to decreased DMI (Li et al., 2020). In an exhaustive meta-study, milk production reliably increased (0.541 kg/d; heterogeneity = 19%) and milk protein production increased (0.02 kg/d) as
FPS decreased, however FCM was not influenced by FPS (Nasrollahi et al., 2015). FPS influences chewing activities and production of milk fat precursors in the rumen and modified milk fat substance and yield of fat-corrected milk (Lu, 1987).

Table 2 - Intake and digestion of organic matter and acid detergent fiber (Firkins et al., 1986).

| Parameter                                      | Forage size | Long   | Chopped | Ground | SEM  |
|------------------------------------------------|-------------|--------|---------|--------|------|
| Organic matter intake (kg/day)                 |             | 13.2   | 12.6    | 13.1   | 0.11 |
| Apparent digestion (% of intake) in total tract|             | 53.7   | 54.3    | 54.7   | 2.11 |
| Apparent digestion (% of intake) in rumen      |             | 28.1a  | 31.2a   | 20.8b  | 2.62 |
| True                                           |             | 57.7   | 56.0    | 55.3   | 4.32 |
| Percent of apparent digestion in the rumen     |             | 52.3a  | 57.4a   | 38.0b  | 2.92 |
| Acid detergent fiber intake (kg/day)           |             | 4.8    | 5.0     | 4.3    | 0.32 |
| Apparent digestion (% in take) in total tract  |             | 36.7c  | 39.7c   | 24.0d  | 2.67 |
| Apparent digestion (% intake) in rumen         |             | 36.0c  | 35.6c   | 16.2d  | 3.10 |
| Percent of total digestion occurring in the rumen|         | 98.0a  | 89.7a   | 67.5b  | 3.21 |

**Treatment means with different superscripts are significantly different (P<0.05); **Treatment means with different superscripts are significantly different (P<0.10).

Table 3 - Intake and digestion of nitrogen and partition of duodenal N flow.

| Parameter                                      | Forage size | Long   | Chopped | Ground | SEM  |
|------------------------------------------------|-------------|--------|---------|--------|------|
| N intake (g/day)                               |             | 422a   | 322b    | 409a   | 9.3  |
| **Non-ammonia nitrogen flow at duodenum**      |             |        |         |        |      |
| g/day                                          |             | 405c   | 337d    | 462a   | 27.0 |
| % of N intake                                  |             | 96c    | 103cd   | 112d   | 4.67 |
| **Feed and endogenous N**                      |             | 37.2c  | 37.5c   | 46.8d  | 3.46 |
| g/day                                          |             | 157ed  | 124c    | 194d   | 14.0 |
| % of N intake                                  |             | 37.2c  | 37.5c   | 46.8d  | 3.46 |
| **Bacterial N at duodenum**                    |             | 248ed  | 212c    | 269d   | 13.6 |
| g/kg OM TROMD *                                |             | 32.5c  | 30.7c   | 37.5d  | 2.39 |
| Post-ruminal N digestion g/day                 |             | 246a   | 203a    | 334b   | 25.7 |
| Apparent N digestion in total tract, % of N intake |         | 5.9c   | 58.3c   | 68.5d  | 2.39 |

*True rumen organic matter digestion; **Treatment means followed by different letters are different (P<0.05); **Treatment means followed by different letters are different (P<0.10).

Table 4 - Ruminal kinetics in steers fed chopped or ground hay.

| Item                                           | Treatment | Chopped   | Ground |
|------------------------------------------------|-----------|-----------|--------|
| Ruminal particulate dilution rate, %/h         |           | 4.73      | 4.72   |
| Ruminal fluid dilution rate, %/h               |           | 1034      | 10.64  |
| Duodenal fluid flow, liters/dc                 |           | 78.8      | 76.5   |
| Ruminal fluid volume, liters/c                 |           | 78.1      | 67.7   |
| Ruminal NH₃, mg/dl                            |           | 14.0      | 15.6   |
| Total ruminal volatile fatty acid concentration, mM |         | 76.1      | 77.5   |
| Acetate, mol/100 mol                           |           | 71.5      | 71.2   |
| Propionate, mol/100 mol                        |           | 16.9      | 16.6   |
| Butyrate, mol/100 mol                          |           | 9.5       | 9.8    |
Feeding maize silage processed at adequate (6 mm; FCS) or abrasive (23 mm; CCS) FPS were fed to 22 lactating Holstein cows had no effect on milk yield (Couderc et al., 2006). These results are partially in alignment with previous studies in previous experiments where reduced FPS did not influence milk yield in advanced lactating dairy cows (Armentano et al., 1988). It was hypothesized that, variation in total tract digestibility and variable retention time may partially compensate for the differences in nutrient intake and mask the lack of effects on milk yield (Couderc et al., 2006). Therefore, because the quality of the fat-corrected milk yield and the particulate passage rate measured were not impaired by the procedure, moderate genetic merit and high variability among the cows used in these studies may restrict the capacity of the cows to react to minor changes in nutritional intake or failure of the statistical model to detect variations in the experiment. Similarly, 16 mid-lactation Holstein dairy animals designated in a 4 × 4 Latin square design with a 2 × 2 arrangement were fed two distinctive chop lengths (shorter = 10 mm or longer = 19 mm) of alfalfa silage and corn silage for a time of 21 days where treatments had no impact on milk yield (Bhandari et al., 2007). The absence of an effect of the FPS of alfalfa silage and corn silage on milk yield resembles earlier studies (Krause et al., 2002b) where alfalfa silage and corn silage exhibited no effect on milk yield. Similarly, corn silage at one-half milk-line stage of maturity and at 0.95-cm theoretical length of cut without processing (control) or 0.95-, 1.45-, or 1.90-cm theoretical length of cut with processing at a 1-mm roll clearance had no effect on milk yield (Bal et al., 2000).

**Microbial protein synthesis**

Increasing peNDF content of diets decreased microbial protein synthesis (Li et al., 2020). Two principal factors impact ruminal digestion of forages, i.e., FPS and level of feed consumption (Firkins et al., 1986). Processing forages usually decreases ruminal fluid-phase dilution rate (D) but elevates particulate D (Weston and Hogan, 1967) and decreases extent of ruminal digestion (Blaxter et al., 1956; Hogan & Weston, 1967). Accelerating feed consumption also results in quicker D (Grovum and Williams, 1977). Accumulative D of particulate or fluid digesta may aggravate efficiency of microbial protein synthesis (MPS) (Bergen et al., 1980). Consequently, FPS and, feed consumption may also affect efficiency of MPS. Studies evaluating effects of feed intake and forage processing in the same experiment (Alwash and Thomas, 1974; Beever et al., 1972) have indicated depressions in ruminal digestion of organic matter (OM) and fiber because of decreased ruminal retention times related with increased feed intake or smaller forage particle size. For ground hay, the digestibility of ADF in the rumen was lower but was partly accounted for by improved digestion of ADF in the hindgut. The duodenum feed flow plus endogenous nitrogen (N) was 37Va and 47Vo on N intake, respectively, with long and field hay. When field hay replaced long hay, MPS efficiency increased by 75Va and post-ruminal N digestion increased by 36Vo. MPS efficiency was positively proportional to the rate of turnover of ruminal solids and inversely related to the rate of liquid dilution. These observations indicate increases in MPS efficacy with either increasing quantities of forage in the diet or improved solid ruminal passage (Rode et al., 1985).

### Rumen Physiology

#### Rumen pH

Four rumen-fistulated cows were randomly assigned in iso-energetic and iso-nitrogenous diets to study the effects of FPS on rumen pH (Rustomo et al., 2006). Expanding forage particle size at the same time increased the most extreme pH for dairy animals which demonstrated that coarse forage particle size can constrict drops in ruminal pH (Figures 5 and 6). In another experiment, expanding FPS increased eating time and decreased eating rate thus even hardly increased FPS was useful to mitigate decline of ruminal pH while profoundly fermentable carbohydrates were offered (Nasrollahi et al., 2014). Decreasing the FPS of corn silage improved rumen pH at 4-5 h after feeding ranging 6.12 to 6.20 (Bhandari et al., 2008).

#### Ruminal fermentation

The impacts of, and associations between, dietary grain source and moderate changes in alfalfa hay (AH) particle size (PS) on digestive processes of dairy cows were assessed (Nasrollahi et al., 2012). The results demonstrated that the minor increment of size of AH delayed eating time and improved rumen fermentation, in particular, feeding regimen in barley cereal. In another study, the peNDF substance of dairy cow eating regimens was altered by differing the FPS of alfalfa silage and impacts on ruminal fermentation (Li et al., 2020). Expanding FPS decreased VFA concentration in rumen.
In alfalfa silage and corn silage based eating regimen, decreasing the chop length of alfalfa silage increased the concentrations of total VFA and the molar extent of acetic acid derivatives in rumen liquor yet did not influence the molar extents of propionate and butyrate and the acetic acid derivatives to propionate proportion (Bhandari et al., 2007). Indeed, the chop length of corn silage did not influence concentrations of total VFA, the molar extents of VFA, and the acetic acid derivatives to propionate proportion in the rumen. Maybe, lessening the FPS may have increased ruminal site of assimilation and VFA production because of increased surface area for microbial attack (Krause et al., 2002a). Likewise, lessening FPS can decrease saliva production and fluid passage rate (Krause et al., 2002a), in this manner.
increasing the concentrations of VFA in the rumen. Further, a decrease of FPS may likewise decrease VFA production (Figure 7) in the rumen because of increased particulate disappearance rate (Soita et al., 2003).

Like Krause et al. (2002b), Kononoff and Heinrichs (2003) found that a decrease of the FPS of hay silage increased the concentration of total VFA in rumen liquid. In any case, as opposed to this study, in these previous experiments, concentration of propionate increased more than that of acetic acid derivatives, which decreased the acetic acid derivatives to propionate proportion. Studies have detailed inconsistent outcomes on the impacts of the FPS of corn silage on rumen VFA. Similarly, it was found that decreasing the FPS of corn silage increased the concentration of total VFA in the rumen. Unlike VFA, decreasing the FPS of corn silage did not influence the rumen alkali concentration (Bhandari et al., 2007). Nevertheless, Kononoff and Heinrichs (2003) and Beauchemin and Yang (2005) did not find that a decrease of the FPS of alfalfa silage and corn silage influenced the outflow rate of fluid and particulate digesta from the rumen. Similarly, it was found that the FPS of corn silage did not influence rumen VFA (Kononoff & Heinrichs, 2003).

CONCLUSION

Optimum forage particle size ensures maximum dry matter intake, reduced feed sorting, extended gut chewing and rumination activities in dairy cows. It further balances rumen pH, ruminal fermentation, forage degradability, fractional passage kinetics of nutrients and feed effectiveness as a whole. Thus, microbial protein synthesizes, body condition score, feed formulation, irrespective of forage type measured on Penn State Particle Separator may be considered optimum for practical dairy feed formulation.

DECLARATIONS

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Authors’ Contribution
I am the sole contributor of the manuscript.

Conflict of Interests
There is no any conflict of interest.

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Animal welfare statement
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