A Simple Method for the Analysis of Particle Sizes of Forage and Total Mixed Rations

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ABSTRACT

A simple separator was developed to determine the particle sizes of forage and TMR that allows for easy separation of wet forage into three fractions and also allows plotting of the particle size distribution. The device was designed to mimic the laboratory-scale separator for forage particle sizes that was specified by Standard S424 of the American Society of Agricultural Engineers. A comparison of results using the standard device and the newly developed separator indicated no difference in ability to predict fractions of particles with maximum length of less than 8 and 19 mm.

The separator requires a small quantity of sample (1.4 L) and is manually operated. The materials on the screens and bottom pan were weighed to obtain the cumulative percentage of sample that was undersize for the two fractions. The results were then plotted using the Weibull distribution, which proved to be the best fit for the data.

Convenience samples of haycrop silage, corn silage, and TMR from farms in the northeastern US were analyzed using the forage and TMR separator, and the range of observed values are given.

(**Key words**: particle size, forage, total mixed ration, analysis)

Abbreviation key: **ASAE** = American Society of Agricultural Engineers.

INTRODUCTION

The need of dairy cows for increasingly higher energy has led to diets that are relatively high in concentrates (19). In addition, diets that are all silage have generally replaced diets with long dry hay for the currently larger herds and more mechanized farms. In addition to other nutrients, cows also require fiber (11). When the minimum fiber requirements are not met, cows often show one or more of the following metabolic disorders: reduced total DM digestibility, reduced milk fat percentage, displaced abomasum, and increased incidence of ruminal parakeratosis, laminitis, acidosis, and fat cow syndrome (20). Cows consuming sufficient NDF with a finely chopped forage can also exhibit the same metabolic disorders as cows fed a diet deficient in fiber (5, 25).

Adequate particle length of forages is necessary for proper ruminal function. Reduced particle size has decreased the time spent chewing and has tended to decrease ruminal pH (27). Sudweeks et al. (20) developed a roughage value index system that estimates the chewing time of a diet using the mean particle size, DM, and NDF. When forage particle length is insufficient, the cows spend less time chewing, decreasing the volume of saliva produced that is needed to buffer the rumen. In a study by Grant et al. (7), the cows fed a finely chopped ration ruminated 2.5 h less than those fed a coarse ration; the shorter rumination decreased bicarbonate production by these cows by 258 g/d.

Insufficient particle size decreases the ruminal acetate to propionate ratio and the pH, which, in turn, lowers milk fat percentage (6, 16, 18, 26). When ruminal pH falls below 6.0, the growth of the cellulolytic organisms is depressed, allowing for an increase in the microbes that produce propionate and a decrease in the acetate to propionate ratio (7).

Reduced forage particle size increases DMI, decreases digestibility, and decreases retention time of solids in the rumen (8, 9, 21). Diets that have a smaller forage particle size enter the rumen at a smaller size after initial chewing and swallowing; therefore, they leave the rumen faster. The result is an increase in the fractional turnover rate of ruminal DM and increased DMI (5, 8, 9, 25). Smaller forage particles spend less time in the rumen for microbial digestion, thereby decreasing digestibility, particularly fiber digestion (21). Furthermore, researchers (15, 21) have found that microbial protein synthesis increases as forage size decreases because of increased ruminal passage of solids. Fractional specific gravity also plays an important role in passage rates of feed particles from the rumen (24).

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The mean particle size and the variation in particle size are important nutritionally to the cow, and, under normal circumstances, the cow consumes particles of many different sizes, which allows for a steadier rate of digestion in the rumen and passage from the rumen (23). A description of the distribution (rather than only the mean) of the length of feed particles is needed for proper nutritional management (10).

Currently, no simple method exists to determine the particle length of forage and TMR. The standard method for determining the particle size distribution of chopped forages is standard S424 of the American Society of Agricultural Engineers (**ASAE**) (2), but this standard is not practical for on-farm evaluations. Nutritionists and farmers need a practical method that is rapid, accurate, and inexpensive for regular use on the farm.

The objectives of this project were to develop a simple method for analysis of forage particle size and to characterize the particle size distribution of a sample of forages and TMR used by farmers in the Northeast.

MATERIALS AND METHODS

A forage and TMR particle size separator was developed to mimic the ASAE standard S424 device (2). The ASAE device is a laboratory-scale separator of forage particle sizes, containing five screens of varying sizes and a bottom pan to separate particles into six unique fractions. The screens of the ASAE device have a width of 406 mm and a length of 565 mm. Nominal openings in the screens are 19.0, 12.7, 6.3, 3.96, and 1.17 mm from the top to the bottom screen, respectively.

The simplified separator has two screens and a bottom pan. The hole sizes were selected to match the expected distribution of feed particles based on results of samples in the ASAE device. Screens were needed to characterize the larger particles that were of interest and to separate the sample into measurable fractions. Because the larger particles were more important, the top screen was selected to measure the larger particles, and the bottom screen was selected to separate the remaining portion nearly equally. These hole sizes also gave two points that were far enough apart to increase the reliability of the slope of the particle size distribution line. The diameters of the hole sizes of the screens were 19 and 8 mm for the top and bottom, respectively, dividing the sample into three portions: material greater than 19 mm in length remaining on the top screen, material between 19 and 8 mm in length on the middle screen, and material less than 8 mm in length on the bottom pan.

Using the same principle as the ASAE device, the top screen with hole sizes of 19 mm had a thickness of 12.2 mm; the screen with hole sizes of 8 mm had a thickness of 6.4 mm. These degrees of thickness were needed to provide a three-dimensional barrier to prevent particles that were larger than the hole size from slipping through.

The material used to make the screens needed to have sufficient strength and rigidity to function after many holes were drilled into it. Furthermore, the material of the screens needed to be light for easy handling, to have little friction and static for free movement of the particles across the screens, and to be inexpensive. The sides and bottom pan were less important and needed to be light, readily available, inexpensive, and easy to construct. In the prototype, polyvinyl chloride sheet plastic was selected for the screens, and plywood was selected for the sides and bottom pan.

The size of forage or TMR sample used also mimicked that used for the ASAE standard. The separator had approximately one-fourth of the surface area of the ASAE device. Therefore, the sample size used was approximately one-fourth of the recommended sample size for the ASAE standard or 1.4 L.

The operation of the separator was simple. First, the screens were stacked, and then the sample of material to be analyzed (1.4 ± 0.5 L) was placed on the top screen. On a flat surface, the separator was shaken horizontally five times in one direction, then rotated one-fourth turn, and again shaken five times. This procedure was repeated for eight sets of five shakes, rotating the same direction between each set. Rotation of the separator ensures thorough separation with a minimum amount of shaking. A shake was considered as a forward and backward motion of the separator over a distance of 17 to 26 cm. The rate of shaking was a movement sufficient to allow all particles of small enough size the opportunity to fall through both sets of screens.

The material remaining in each section was weighed (scale accurate to 1 g), and the percentages of particles were plotted on Weibull paper with the horizontal axis for particle size and the vertical axis for the cumulative percentage of the sample that was undersize. Samples of corn silage, haycrop silage, and TMR (including grains) were used to compare the separator with the ASAE device. Subsamples of each sample were analyzed three times on the simplified separator and four times on the ASAE device. A *t* test comparison was used to analyze the data (17).

Convenience samples from eight states in the Northeast (predominately from Pennsylvania) were used to describe the particle sizes of forage and TMR commonly used on some farms. Samples included haycrop silage, corn silage, and TMR. Haycrop and corn silages were analyzed for CP, NDF, and ADF with near infrared reflectance spectroscopy (12). The TMR samples containing 40 to 60% forage were also analyzed. There were 32 samples of corn silage ($\overline{X} \pm$ SD: 39.5 ± 7.88% DM, 10.0 ± 2.33% CP, 49.9 ± 5.09% NDF, and 28.6 ± 3.69% ADF), 33 samples of haycrop silage (48.5 ± 13.83% DM, 19.35 ± 3.79% CP, 45.6 ± 8.58% NDF, and 34.9 ± 5.74% ADF), and 26 samples of TMR.

RESULTS AND DISCUSSION

The data from the separation of particles with the ASAE device were plotted on log normal probability graph paper and Weibull graph paper. The use of the Weibull distribution was more linear, thereby having numerically higher coefficients of determination (using five points fitted to a two-parameter model) for each sample, and not requiring data transformation to a log scale, thereby being easier to plot and to interpret (Table 1). Statistical differences were not found in all cases because of the large variance associated with using log normal distribution. Our results agreed with those of Pitt (13) and Vaage and Shelford (22), who demonstrated that the Weibull distribution best fit the data of forage particle size distribution. In addition, the gamma distribution (1) and an exponential distribution (14), both of which are related to Weibull, were found to fit the distribution of forage particles better than the log normal graph. This result is contrary to the current ASAE standard S424 (2), which recommends the use of the log normal distribution for forage only samples.

Comparison of the results between the ASAE device and the newly developed separator with a paired *t* test indicated no difference in predicting fractions of particles less than 19 or 8 mm in maximum dimension in 21 of the 36 statistical tests (Table 2). The standard deviations of samples analyzed with the two separators were very low, thereby causing differences when the mean values were quite similar.

The mean absolute difference between separators with the five samples of haycrop silage, corn silage, and TMR, respectively, were 2.40, 2.79, and 0.68% for particles less than 19 mm and 6.23, 1.99, and 2.82% for particles less than 8 mm, respectively. Based on these limited data, TMR samples had lower absolute differences than the haycrop and corn silage samples. Also, with these samples, the mean absolute difference of particles less than 19 mm was 1.96%. These differences were likely within the realm of sampling error. The results from the two separators were more uniform when measuring larger forage particles, which are more important to the ruminant because they stimulate greater rumination and have a greater

TABLE 1. Means and *t* test comparison of the log normal and Weibull graph with coefficients of determination using the standard S424 device of the American Association of Agricultural Engineers.[1]

	r^2				
Sample	Log normal		Weibull		P^2
	$\overline{X}$	SD	$\overline{X}$	SD	
Haycrop silage 1	0.635	0.458	0.997	0.0008	0.212
Haycrop silage 2	0.583	0.418	0.960	0.0256	0.179
Haycrop silage 3	0.864	0.048	0.993	0.0010	0.012
Haycrop silage 4	0.638	0.343	0.989	0.0007	0.134
Haycrop silage 5	0.584	0.338	0.976	0.0104	0.098
Fresh haycrop silage 1	0.885	0.050	0.999	0.0000	0.020
Corn silage 1	0.665	0.393	0.994	0.0007	0.192
Corn silage 2	0.833	0.063	0.979	0.0128	0.015
Corn silage 3	0.787	0.116	0.973	0.0047	0.048
Corn silage 4	0.606	0.374	0.992	0.0007	0.132
Corn silage 5	0.700	0.305	0.983	0.0015	0.160
Fresh corn silage 1	0.635	0.376	0.987	0.0038	0.159
Rye silage 1	0.784	0.199	0.998	0.0020	0.121
TMR 1	0.807	0.101	0.942	0.0035	0.076
TMR 2	0.830	0.081	0.993	0.0019	0.028
TMR 3	0.864	0.074	0.984	0.0028	0.050
TMR 4	0.848	0.101	0.984	0.0019	0.076
TMR 5	0.843	0.006	0.988	0.0009	0.000

[1] Four subsamples were analyzed for each sample and plotted on log normal and Weibull graphs.

[2] Obtained using a two-tailed *t* test.

impact on intake behavior than the smaller particles do (10).

The ASAE standard S424 (2) is a method originally designed to determine the particle size of chopped forage material only; however, TMR analysis is important for formulation of practical dairy rations. An analysis was also performed on haycrop silages with extremely high DM content and TMR containing long dry hay in both separators; results were identical. For both the ASAE device and the simplified separator, some particles that were longer than the diameter of the hole size passed through the screen above the material. The light hay particles did not remain on a horizontal plane but instead became vertical, which allowed some to pass through the holes more easily.

The repeatability of both the simplified separator and the ASAE device was high. Subsamples of a forage of TMR sample were analyzed three to four times on the separator and ASAE device. The data from these analyses were essentially the same from one subsample to another. The high repeatability of each device is demonstrated by the low standard deviations (Table 2).

Data points collected using the separator can be plotted on Weibull paper for interpretation. The line connecting these points can be extended past the points for extrapolation; however, the reliability of the extended line decreases as the distance from the data points increases. The line can then be used to find the percentage of particles under any forage or TMR particle size that is thought to be important. Because the distribution of particle sizes is important, a line describing the distribution is more useful and thorough than a simple statement of the mean particle size (obtained by finding the particle size at 50% cumulative probability). Perhaps more useful than mean particle length is the percentage of particles in a ration that are larger than some critical value (e.g., 19 or 25 mm).

The slope of the line on a Weibull graph indicates the distribution of particle sizes in that feedstuff. A steep slope indicates a narrow range (most particles being very similar in size), and a gentle slope indicates a wide range (most particles being very different in size) of particle sizes.

Data for corn silage, showing the shortest, mean, and longest particle sizes (Figure 1), demonstrate the wide range of particle sizes currently being used by farmers. The lines for the corn silage that describe the distribution at a particle length of 20 mm, showed the cumulative percentage of the sample that was undersize to be 40, 78, and 94 for the coarsest, mean, and finest chopped samples, respectively. The haycrop silages (Figure 2) yielded different results with 80, 94, and 99.7% of the particles less than 20 mm for the coarsest, mean, and finest chopped samples, respectively. The TMR (Figure 3) had particle sizes that were shorter than those of the haycrop and corn silages, which was primarily because of the addition of grain, and the line describing the TMR samples showed that 87, 95, and 99% were smaller than 20 mm for the coarsest, mean, and finest chopped samples, respectively.

In the past, researchers have used the theoretical length of cut of a forage to describe the general particle size of the forage that the cows were consuming but not the actual particle size (3). After a forage is chopped, it may be handled by many pieces of mechanical equipment that further reduce the particle size. In particular, silo unloaders and TMR mixers often grind and churn the forage particles, reducing

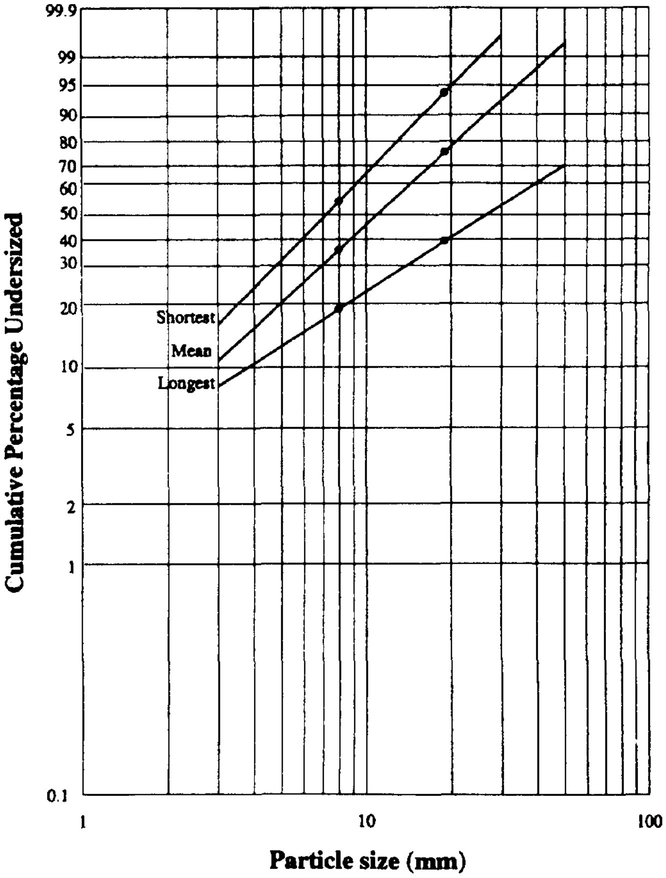

Figure 1. Distribution of the shortest, mean, and longest of 32 corn silage samples.

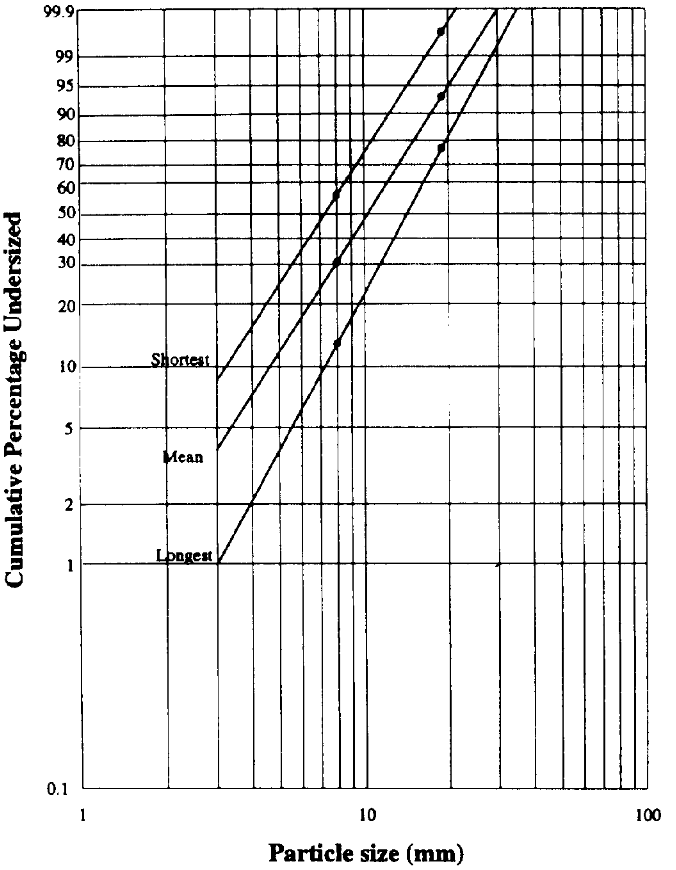

Figure 2. Distribution of shortest, mean, and longest of 33 haycrop silage samples.

the size. A forage chopper may have been set to deliver a theoretical length of cut of 34 mm. Even with such a relatively long chop length, many particles would be smaller than 10 mm, and subsequent handling and processing further reduces particle sizes. For this reason, nutritional research focusing on particle size necessitates sampling at feeding rather than at harvest.

To promote the maximum performance of dairy cows, both the chemical and physical components of the fiber source should be considered. Currently, the NRC (11) only considers the chemical requirement for fiber; however, the physical form of the feedstuff plays an important role in stimulating chewing and maintaining normal ruminal function (20). Beauchemin et al. (4) found that diets with longer particle length that were formulated below NRC (11) minimum forage fiber requirements increased milk production and had minimal effects on DMI and milk fat content. Forage particle length and distribution may be useful in formulating diets that are low or marginal in NDF content. Further research is needed to determine the best relationship of fiber to particle size to maximize the performance of dairy cattle throughout different stages of life and lactation.

CONCLUSIONS

The simple method described herein was developed to measure particle sizes of forage and TMR and should become a feedstuff analysis as common as any of the chemical or fiber analyses. By using the separator, diets could be sampled and analyzed to characterize the particle size distribution. This simple analysis might explain effects that have been caused by particle sizes of forage or TMR. Furthermore, reports of nutritional research trials should document particle size as consumed by the animals, not as indicated by machine settings.

The newly developed separator has many advantages over the ASAE device, including less time to perform an analysis, ease of operation, and its small, portable size. This device allows forage and TMR particle sizes to be measured directly on farms.

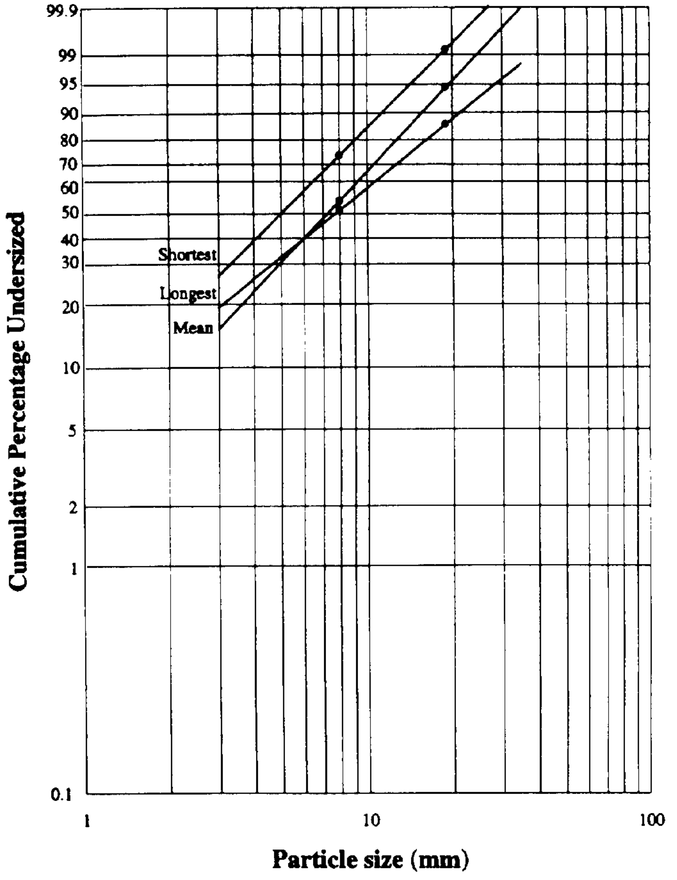

Figure 3. Distribution of the shortest, mean, and longest of 26 TMR samples.

TABLE 2. Means, standard deviations, and *t* test comparison of the standard S424 device of the American Society of Agricultural Engineers (ASAE) and the simplified separator with the percentage of particles that were less than 19 and 8 mm.[1]

Sample	ASAE Device				Simplified separator				P^2	
	Percentage <19 mm		Percentage <8 mm		Percentage <19 mm		Percentage <8 mm		19 mm	8 mm
	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD		
Haycrop silage 1	92.99	1.10	53.66	3.71	94.86	1.57	48.42	2.50	0.121	0.091
Haycrop silage 2	80.74	8.29	44.80	6.67	82.84	0.84	45.17	0.60	0.688	0.930
Haycrop silage 3	95.17	0.37	58.95	1.34	92.20	1.24	47.02	1.10	0.006	0.000
Haycrop silage 4	97.83	0.18	76.25	3.03	97.39	0.88	68.60	0.86	0.364	0.009
Haycrop silage 5	80.39	2.88	32.61	2.30	75.79	4.71	26.64	2.89	0.167	0.028
Fresh haycrop silage 1	95.60	0.13	69.42	0.69	90.35	0.57	57.61	1.31	0.000	0.000
Corn silage 1	98.61	0.23	58.34	1.47	99.23	0.32	59.74	2.72	0.029	0.417
Corn silage 2	94.67	3.51	50.85	2.70	97.78	0.05	53.06	0.45	0.195	0.230
Corn silage 3	86.89	4.36	32.59	3.11	92.67	2.55	33.21	1.84	0.100	0.774
Corn silage 4	91.52	0.68	38.89	0.87	95.21	1.59	41.75	1.47	0.008	0.023
Corn silage 5	90.19	1.29	26.50	2.93	91.48	1.91	29.34	0.84	0.328	0.172
Fresh corn silage 1	90.37	2.58	26.03	2.38	89.47	0.02	20.47	2.11	0.583	0.024
Rye silage 1	87.11	3.08	38.26	2.76	81.45	3.66	38.89	1.74	0.076	0.745
TMR 1	98.28	0.13	54.96	1.15	99.06	0.34	56.99	0.77	0.007	0.048
TMR 2	97.75	0.41	71.72	2.97	98.20	0.45	72.11	1.53	0.228	0.843
TMR 3	96.69	1.05	60.21	1.11	97.27	0.55	61.21	1.82	0.436	0.402
TMR 4	96.21	0.43	63.76	0.90	95.07	0.17	58.51	0.44	0.008	0.000
TMR 5	92.90	0.63	47.15	0.27	93.37	0.93	41.70	2.07	0.453	0.003

[1] Subsamples were analyzed four times with the ASAE device and three times with the simplified separator.

[2] Obtained using a two-tailed *t* test.

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