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Accuracy and physical characteristics of total mixed rations and feeding sorting behavior in dairy herds of Castro, Paraná

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ABSTRACT - The objective of this study was to assess the accuracy of the content of total mixed rations (TMR) offered to high-producing cows from 20 dairy herds of Castro, Paraná State, Brazil. The average milk yield during the sample collection period was 38.0±6.8 kg/day, with 3.47±0.25% milk fat and 3.05±0.18% milk protein. The particle size distribution of samples of fresh diet and leftovers was evaluated using the Penn State Particle Separator (PSPS) and chemical analysis was also conducted. The TMR homogeneity was estimated by the coefficient of variation (CV) of particles retained on the two intermediary sieves (<19 and >1.18 mm), in which a CV higher than 5% indicated a poorly mixed TMR. The TMR offered exceeded the formulated TMR only for NDF (+7.3%) and was lower than the formulated TMR for CP (−6.5%), ADF (−10.1%), and ash (−18.6%) contents. These differences are due to daily variations in feed quality, mixing equipment, and ingredient mixing order, mostly for forage. Differences between leftovers and TMR offered were substantial: −9.4% for CP, +25.1% for NDF, +31.6% for ADF, and +13.1% for ash, suggesting a feed sorting effect against long forage particles and in favor of small concentrate particles. The proportion of the offered TMR retained in the top PSPS sieve showed positive correlations with NDF (r = 0.58) and ADF (r = 0.54) contents of the refusals, which indicates that cows sort against long particles. Positive correlations were also found between the CV in the second sieve and NDF (r = 0.56) and ADF (r = 0.47) contents of refusals, suggesting that poorly mixed diets are more easily sorted by cows. Therefore, evaluating the chemical and physical properties of TMR, especially for forage, is extremely important for providing a consistent diet.

Keywords: dairy cattle, particle size, nutrition

1. Introduction

The topic of precision nutrition has gained importance in the dairy industry over the last decades. The basic principles of this concept aim to attend the nutritional requirements of animals without excesses or deficiencies, maximizing the use of nutrients, reducing the impact of their environmental excretion, and making their production more profitable. Properly formulated diets that meet the requirements for high milk yields without nitrogen and phosphorus overfeeding are the first steps required to minimize their excretion into the environment as well as to decrease feed costs (González et al., 2018).

In the context of formulating diets with an improved accuracy, it is assumed that on a dairy farm, there are basically three diets: the nutritionist's diet, formulated to meet the cow's requirements; the diet mixed by the farm, in which the ingredients are loaded into the mixing wagon and delivered to the cows; and the diet that the cows actually consume (Almeida et al., 2013; Rossow and Aly, 2013).

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To achieve three similar diets, Almeida et al. (2013) highlighted the practice of monitoring the quality of total mixed rations (TMR). The objective of mixing all the ingredients and offering them to the animals via TMR is that the flow of the nutrients in the rumen is more constant during the day, improving the synchronism between energy and protein and, consequently, feed utilization (Schingoethe, 2017). The quality of the mixture also influences the diet consumed by the animals. The lack of a properly mixture generate different distribution and concentrations of nutrients along the feed bunk, and the undesirable selection of ingredients could even be facilitated (Zebeli et al., 2012).

It is known that variation among diets impacts milk production, but how intense the effect is and what levels of variation are acceptable without loss of performance remain little studied or unknown (Stone, 2008; Rossow and Aly, 2013; Tebbe and Weiss, 2020). Therefore, it is important to evaluate variations occurring within commercial dairy farms, their main causes and their effects on milk production and composition.

Based on that, the primary goal of the current study was to compare the formulated, the offered, and the consumed diet provided to high-producing cows on commercial dairy farms and, consequently, compare their similarities. A second goal was to analyze the homogeneity of the TMR, the mean particle size in the offered diets, and the correlations among physical aspects of the offered diets with their chemical composition and their respective leftovers.

2. Material and Methods

The current study evaluated 20 farms located in Castro (latitude: 24°47'28" S, longitude: 50°00'43" W, and altitude: 999 m), Paraná State, Southern Brazil, during November 2013. On 11 of these farms, cows were housed in a free-stall barn system, and the remaining nine farms operated a semi-confinement system, where the animals had access to the paddocks only for resting, and all the diet was offered in the feed bunk. The common forage sources for all evaluated farms were corn silage and oat or ryegrass haylages; on 11 farms, oat hay or wheat straw was added to lactating diets. All of them used TMR.

The farms were visited only once, when the evaluated diets were collected from the high-producing groups of each herd, all composed only by Holstein cows. The farms had 217±162 lactating cows with 206±25 days in milk, and 2.2±0.3 lactations on average. Milk production of the evaluated groups was 38.0±6.8 kg/cow/day, with minimum and maximum yields of 25.0 and 50.8 kg/cow/day, respectively. The average milk fat and protein contents were 3.47±0.25 and 3.05±0.18% respectively, with milk fat ranging from 2.98 to 4.00% and milk protein from 2.81 to 3.44%.

During the visit, aspects involving the diet mixing process were monitored and registered to understand how the farms performed. Those aspects were loading order of the ingredients, in which we considered as adequate the following sequence: first the addition of drier forages, as hay or haylage, followed by minerals and concentrates, with corn silage being added in sequence, then ending up with liquid feeds. The mixing time was also monitored, registered from the moment that the last ingredient was loaded until the end of the mixture. Finally, to complete the evaluation of the diet mixing process, the final loading of the wagon was analyzed, which was used to determine the percentage of its maximum loading capacity.

Immediately after the TMR was delivered to the cows, 10 samples of approximately 500 g each were collected along the entire length of the feed bunk at equidistant spots. These samples were homogenized in a bucket to get a pooled sample of 500 g that was immediately frozen for further chemical analysis. In addition, 10 other samples of approximately 500 g were collected also at equidistant spots along the length of the feed bunk and individually stored in plastic bags for later evaluation of the TMR homogeneity and the distribution of the average particle size, using the Penn State Particle Separator (PSPS).

The use of PSPS followed the methodology described by Heinrichs and Kononoff (2002), using about 500 g of sample per evaluation. There were five back and forth movements that were repeated eight times for each side of the sieve, totaling 40 movements. The mass remaining in each of the sieves was weighed to calculate the proportion of each portion according to each sieve. This three-sieve PSPS

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model separated samples into four fractions: long (>19 mm), medium (<19 and >8 mm), short (<8 and >1.18 mm), and fine (<1.18 mm) particles. This process was performed with all 10 samples, on the farm and always by the same person, immediately after sampling. Shortly before the next feed delivery, a sample of leftovers was collected from several points along the feed bunk, for later chemical analysis.

The farms' nutritionists kindly provided the composition of the formulated diet, which were formulated using the AMTS.Cattle.Professional nutrition software.

The samples of offered diets and their respective leftovers were analyzed to determine their chemical composition. Before the analysis, samples were dried at 65 °C for 72 h and then ground in a Wiley Miller stationary mill with 1-mm sieve. The analysis performed were the dietary dry matter (DM) (105 °C; AOAC International, 2000; method 930.15) and ash content (Ash%DM) (535 °C; AOAC International, 2000; method 942.05). The neutral detergent fiber (NDF%DM) and acid detergent fiber (ADF%DM) fractions were determined according to Van Soest et al. (1991) methodology adapted to the sequential method using ANKOM Fiber Analyzer (ANKOM® Technology Corp.). The determination of crude protein (CP%DM) (N×6.25; AOAC International, 2000; method 990.03) content was performed using the micro-Kjeldhal method.

Simple descriptive statistics such as means, standard deviations, coefficients of variation, and minimum and maximum values were calculated for the chemical composition data and distribution of the average particle size of the evaluated diets using PROC MEANS from SAS software (Statistical Analysis System, version 9.0). Simple correlations were determined using PROC CORR of SAS for the variables distribution on PSPS sieves 1 (long), 2 (medium), 3 (short), and bottom (fine) (%Sieve1, %Sieve2, %Sieve3, and %Bottom) and their respective coefficients of variation (CV Sieve1%, CV Sieve2%, CV Sieve3%, and CV Bottom%); also, for the concentrations of DM, CP, NDF, ADF, and ash of the formulated diet (DMf, CPf, NDFf, ADFf, and ASHf); and for the contents of the offered diet (DMo, CPo, NDFo, ADFo, and ASHo) and their leftovers (DMl, CPl, NDFl, ADFl, and ASHl) as well.

3. Results

The chemical profile of formulated, offered, and leftover diets is described on Table 1; the difference between the offered diet and the formulated diet (Diff.1) was −0.82 percentage points for DM, −1.04 for CP, 2.43 for NDF, −1.93 for ADF, and −1.34 for ash. The highest differences between the formulated and the offered diets were observed in NDF, ADF, and ash: +7.28, −10.07, and −18.62%, respectively (Figure 1).

The wide variation in the range (Min–Max) of Diff.1 among all the chemical variables of the offered and formulated diets shows that there is wide variation among farms in these parameters. For example, the Diff.1 for CP (%) had an average of −6.45%, but ranged from −23.40 to +13.14%.

The differences between the leftovers and the offered diet (Diff.2) for the chemical variables were −1.91 percentage points for DM, −1.40 percentage points for CP, 8.88 percentage points for NDF, 5.24 percentage points for ADF, and 0.74 percentage points for ash.
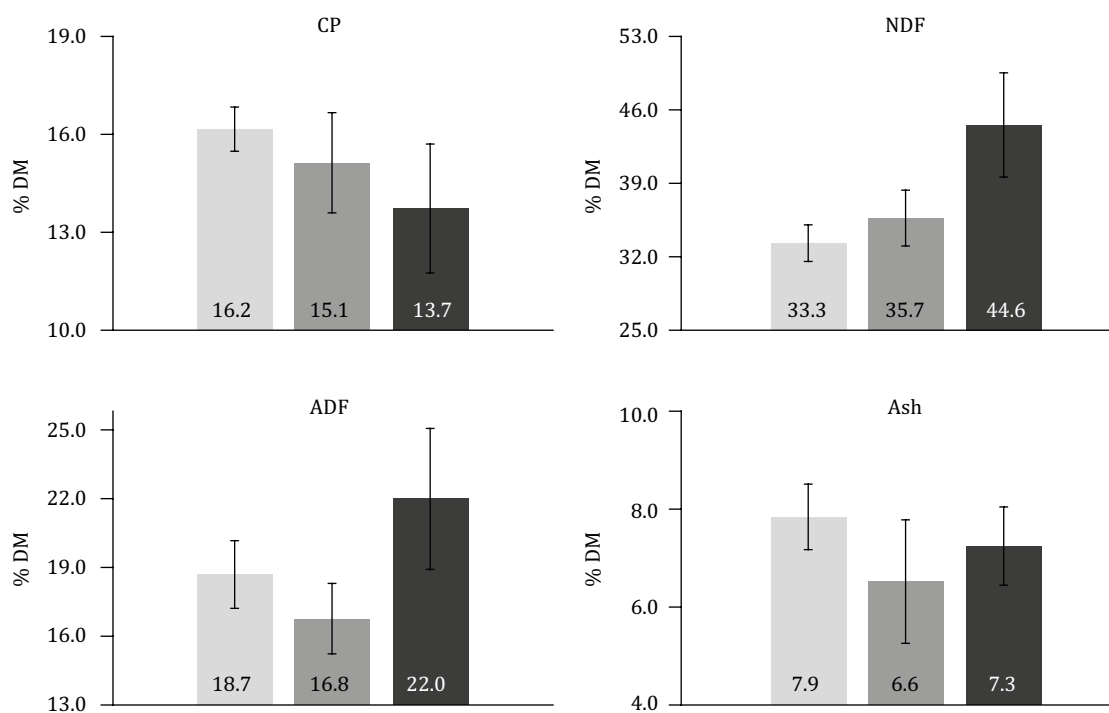
Table 1 - Means, standard deviations, and variation (min–max) of the chemical variables of the formulated and offered diets and their leftovers

	Formulated				Offered				Leftovers			
	Mean	SD	Min.	Max.	Mean	SD	Min.	Max.	Mean	SD	Min.	Max.
DM (%)	49.07	3.71	43.40	56.75	48.25	4.43	36.86	57.67	46.34	4.34	35.17	56.36
CP (%DM)	16.18	0.67	15.00	17.50	15.14	1.53	11.72	17.74	13.74	1.98	10.71	16.78
NDF (%DM)	33.30	1.74	30.20	36.30	35.73	2.65	29.25	40.25	44.61	5.01	35.29	53.25
ADF (%DM)	18.70	1.49	16.23	21.28	16.77	1.54	14.14	19.94	22.01	3.09	17.46	27.90
Ash (%DM)	7.89	0.68	6.85	8.85	6.55	1.29	4.74	10.98	7.29	0.81	5.86	9.08

DM - dry matter; CP - crude protein; NDF - neutral detergent fiber; ADF - acid detergent fiber; Min. - minimum; Max. - maximum; SD - standard deviation; Ash - ashes.

The higher NDF and ADF contents in the leftovers compared with the offered diets were 25.07 and 31.63%, respectively, with extreme herds having 53 and 78% higher contents of NDF and ADF in the leftovers, compared with their respective offered values.

The average percentage retained by sieves 1 (>19 mm), 2 (>8 mm), 3 (>1.18 mm), and bottom (<1.18 mm) was 19.23, 39.58, 28.91, and 12.30%, respectively (Table 2). Moderate correlations (P<0.05) were observed between %Sieve1 and ADFo content (r = 0.49), %Sieve2 and DMo content

CP - crude protein; NDF - neutral fiber detergent; ADF - acid fiber detergent; Ash - ashes; DM - dry matter.

Figure 1 - Means and standard deviations of the chemical variables of the formulated (light gray columns) and offered (gray columns) diets and their respective leftovers (black columns).

Table 2 - Means, standard deviations (SD), and variation (min–max) of the proportions of the offered diet retained in each Penn State Particle Separator sieve, its respective coefficient of variation (CV) among 10 feed bunk points, mean particle size (MPS), and standard deviation of the mean particle size (SDMPS)

Variable	N	Mean	SD	Min.	Max.
Sieve 1 (%)	20	19.23	7.50	3.80	30.00
Sieve 2 (%)	20	39.58	7.16	25.40	54.50
Sieve 3 (%)	20	28.91	4.77	22.10	37.50
Bottom (%)	20	12.30	4.20	3.10	25.00
Sieves 1+2 (%)[1]	20	58.80	6.26	49.30	73.90
CV Sieve 1 (%)	20	16.27	11.54	7.00	59.00
CV Sieve 2 (%)	20	5.36	3.26	2.40	14.30
CV Sieve 3 (%)	20	4.12	1.65	2.10	8.10
CV Bottom (%)	20	5.30	2.38	1.90	12.30
MPS (mm)	20	9.35	1.26	7.11	12.70
SDMPS (mm)	20	2.22	0.16	1.88	2.44

[1] Sieve 1 (%) + Sieve 2 (%).
Min - minimum; Max - maximum.

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(r = −0.46), %Bottom and DMo (r = 0.47) and CPo contents (r = 0.49), and MPS and CPo (r = −0.53) and ADFo contents (r = 0.46). The highest correlation magnitude (P<0.01) was found between %Sieves 1+2 and CPo content (r = −0.66) (Table 3).

Moderate correlations (P<0.05) were found between %Sieve1 and ADFl (r = 0.54) and Ashl (r = 0.45) contents, %Sieve3 and CPl content (r = 0.46), %Bottom and Ashl content (r = −0.45), and %Sieves 1+2 and CPl (r = −0.54) and Ashl (r = 0.56) contents. The highest correlations (P<0.01) were found between %Sieve1 and NDFl content (r = 0.58) and between MPS and Ashl content (r = 0.61) (Table 4). Significant correlations (P<0.05) were found between CV Sieve2 and NDFl (r = 0.56) and ADFl (r = 0.47) contents, and between SDMPS and NDFl (r = 0.54) and ADFl (r = 0.54) contents (Table 5).

Table 3 - Pearson's simple correlation between the proportion retained in each Penn State Particle Separator sieve and the mean particle size (MPS) of the offered diet with the chemical variables of the offered diet

	DMo (%DM)	CPo (%DM)	NDFo (%DM)	ADFo (%DM)	Asho (%DM)
Sieve 1 (%)	0.17	−0.22	0.26	0.49*	0.31
Sieve 2 (%)	−0.46*	−0.29	−0.09	−0.31	0.03
Sieve 3 (%)	0.02	0.36	−0.16	−0.19	−0.40
Bottom (%)	0.47*	0.49*	−0.14	−0.14	−0.15
Sieves 1+2 (%)[1]	−0.33	−0.66**	0.21	0.24	0.40
MPS (mm)	−0.24	−0.53*	0.31	0.46*	0.42

DM - dry matter; DMo - dry matter of the offered diet; CP - crude protein of the offered diet; NDFo - neutral detergent fiber of the offered diet; ADFo - acid detergent fiber of the offered diet; Asho - ashes of the offered diet.
[1] Sieve 1 (%) + Sieve 2 (%).
* P<0.05; ** P<0.01.

Table 4 - Pearson's simple correlation between the proportion retained in each Penn State Particle Separator sieve and the mean particle size (MPS) of the offered diet with the chemical variables of the leftovers

	DMl (%DM)	CPl (%DM)	NDFl (%DM)	ADFl (%DM)	Ashl (%DM)
Sieve 1 (%)	0.07	−0.37	0.58**	0.54*	0.45*
Sieve 2 (%)	−0.21	−0.09	−0.42	−0.42	0.02
Sieve 3 (%)	−0.07	0.46*	−0.33	−0.35	−0.34
Bottom (%)	0.32	0.28	0.07	0.15	−0.45*
Sieves 1+2 (%)[1]	−0.16	−0.54*	0.21	0.17	0.56*
MPS (mm)	−0.11	−0.36	0.20	0.14	0.61**

DM - dry matter; DMl - dry matter of leftovers; CPl - crude protein of leftovers; NDFl - neutral fiber detergent of leftovers; ADFl - acid detergent fiber of leftovers; Ashl - ashes of leftovers.
[1] Sieve 1 (%) + Sieve 2 (%).
* P<0.05; ** P<0.01.

Table 5 - Pearson's simple correlation between the coefficient of variation (CV) of the Penn State Particle Separator sieves along the feed bunk and the standard deviation of the mean particle size (SDMPS) of the offered diet with chemical variables of the leftovers

	DMl (%)	CPl (%DM)	NDFl (%DM)	ADFl (%DM)	Ashl (%DM)
CV Sieve 1 (%)	−0.22	0.28	−0.28	−0.32	−0.03
CV Sieve 2 (%)	0.02	−0.16	0.56*	0.47*	0.12
CV Sieve 3 (%)	0.05	−0.28	0.26	0.33	0.33
CV Bottom (%)	−0.19	−0.13	0.36	0.20	0.36
SDMPS (mm)	0.42	−0.00	0.54*	0.54*	−0.04

DM - dry matter; DMl - dry matter of leftovers; CPl - crude protein of leftovers; NDFl - neutral detergent fiber of leftovers; ADFl - acid detergent fiber of leftovers; Ashl - ashes of leftovers.
* P<0.05.

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The aspects used to evaluate the mixing process had the following results: on average, 5.61 min were used to mix the diet after adding the last ingredient, with 55% of the farms mixing between 3 and 5 min, 40% more than 5 min, and 5% less than 3 min. Regarding the loading order, only 55% of the evaluated farms followed the loading order considered adequate in our study. The average percentage of loading of the mixers was 55% of their maximum load capacity, in which 60% of the farms underloaded the equipment (< 60% of its maximum capacity), and 15% overloaded the mixer (> 80% of its maximum capacity).

4. Discussion

In a similar observational study, Rossow and Aly (2013) found similar results for the differences between NDF and ash contents of the offered and formulated diets on five farms in California, where the offered diet was 7.27% higher in terms of NDF content and 10.95% lower in terms of ash content than the formulated diet. Endres and Espejo (2010) also observed the same trend when comparing the composition of the offered and formulated diets. In their study, CP and NDF levels of the offered diets were 2.23% lower and 2.68% higher than those of the formulated diets, respectively. Both studies suggest that the probable reasons of these differences are a function of the day-to-day variation in feed quality, also demonstrated by Weiss et al. (2012) and Kertz (1998), errors in the analysis of the chemical composition of the ingredients, and errors in the diet mixing process.

An additional possible explanation for the increase in NDF content in the offered diet when compared with the formulated one happened at the forage loading moment, which tends to be larger than the errors in concentrate ingredients, as their proportion on an as-fed basis of the diet is greater. The process of loading forage (usually corn silage and grass haylage) is usually done with the aid of a wheel loader, an imprecise method that often leads to larger quantities being loaded than the formulated diet requires (Šístkova et al., 2015). These ingredients, mainly corn silage, are generally richer in NDF and poorer in CP compared with concentrated feeds, explaining why the overloading of forage leads to higher NDFo and lower CPo contents.

Endres and Espejo (2010) compared the composition of offered diets and their respective leftovers on 50 dairy farms in Minnesota, United States, and found very similar trends to those observed in the present study. In their case, the differences between leftovers and the offered diet were −5.18% for the DM, 22.2% for the NDF, and −9.14% for the CP levels. According to them and several other authors (Martin, 2000; Leonardi and Armentano, 2003; DeVries et al., 2007), the increase in NDF content and the reduction in CP content in leftovers when compared with the offered diet is explained by selection against long particles, which is composed basically by forage.

Endres and Espejo (2010) also associated the lower DM content of the offered diet with the increase in NDF in the leftovers. This occurs due to selection by the animals against forage (rich in NDF and with lower DM content) and in favor of concentrated feeds (with higher DM content), resulting in a greater proportion of dietary forage that remains in the feed bunk and, consequently, would contribute more to the final DM. This effect even compensates for the natural moisture loss in the leftovers over time, particularly on warmer and drier days.

There was a wide range of Diff.2 values for almost all chemical parameters, suggesting that the degree of feed selection done by the animals varied greatly among farms. This wide variation in selective behavior among herds may be attributed to factors such as dietary DM content, number of meals offered per day, feed bunk linear space per animal, season of the year, and, in particular, the average particle size (Miller-Cushon and DeVries, 2017; Sova et al., 2014; Leonardi and Armentano, 2007; Leonardi et al., 2005).

Concerning TMR particle size, the recommendations of Heinrichs and Kononoff (2002) for the distribution in PSPS sieves is 2-8% in sieve 1, 30-50% in sieve 2, 30-50% in sieve 3, and less than 20% in the bottom pan. In the present study, after using the PSPS to evaluate the offered diet, only one of the 20 farms had less than 8% of particles in sieve 1, as recommended by Heinrichs and Kononoff (2002).

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Concerning sieve 2, three had less than 30%, 16 between the recommended 30 and 50%, and one above 50%. In sieve 3, 11 had less than 30%, and 9 between the recommended 30 and 50%. Finally, 19 farms had less than 20% of particles in the bottom pan. According to the authors, values above 8% in sieve 1 (greater than 19 mm) favor the process of selection against long particles, leading to possible reductions in NDF and physically effective NDF (peNDF) intakes.

Several authors (Martin, 2000; DeVries et al., 2007; Endres and Espejo, 2010; Tayyab et al., 2018) reported that cows selected mainly against particles retained in sieve 1, where the particle size is above 19 mm. This selection can pose a risk for ruminal pH maintenance, as NDF and peNDF intakes may decrease, whereas the concentrate intake, with a higher proportion of rapidly fermentable carbohydrates, may increase (Miller-Cushon and DeVries, 2017). The importance of peNDF levels in the dairy cow's diet in relation to ruminal pH maintenance, stimulation of rumination and saliva production, dietary fiber digestion and its consequent utilization, and microbial protein production, has been well described (Mertens, 1997). However, for these beneficial effects to occur, the physically effective fiber must be consumed indeed. The high and positive correlations observed between %Sieve1 and ADFl and NDFl contents, along with the high and negative correlations between %Sieves 1+2 and CPl content, demonstrate that cows selected against long particles, and the greater the proportions retained in Sieve1 and Sieves 1+2, the greater the NDFl and ADFl levels, and the lower the CPl content.

Many farmers used to believe that the physically effective dietary fiber is the proportion of material retained in sieve 1, clearly demonstrated by Tayyab et al. (2018), who evaluated 50 farms in the UK which included large proportions of grass silage with extremely long particles, leading to an average proportion of 37.8% of particles larger than 19 mm in the offered diet. However, several authors (Heinrichs and Kononoff, 2002; Kononoff et al., 2003; Zebeli et al., 2012) have shown that a particle greater than 4-6 mm is sufficient to stimulate rumination, since this size prevents it from escaping the rumen. According to Armentano (2010), when the sum of the proportions retained in sieves 1 and 2 (Sieves 1+2) is greater than 50%, intake may be limited by physical filling of the rumen, and thus the production of volatile fatty acids would also be limited, reducing the cows' energy supply and potentially compromising milk production. Haselmann et al. (2019) support this hypothesis by finding in their study an increase of 1.8 kg of DM intake by reducing the particle size of the diet (73.5 vs. 23% of particles larger than 19 mm), consequently increasing by 2.3 kg of milk per day, with no change in milk solids contents.

Among the 20 farms monitored, only two had Sieves 1+2 proportions below 50%; in contrast, the highest value was 73.9%. According to Heinrichs et al. (1999), the length of the forage after harvesting is frequently excessively long, which compromises the homogeneity of the diet and facilitates sorting by animals. The same authors mentioned that longer forage reflects a decrease in operational performance, thus reducing energy costs, because finer particles demand better machinery performance. While it would be desirable to chop the forage more intensively during the harvest process, performance and reduction of costs are frequently prioritized, penalizing the quality of the process instead of its yield.

Almeida et al. (2013) emphasized that the quality of TMR is one of the key points to control, so that all the three diets (formulated, offered, and consumed) must have similar values. The homogeneity of mixing also influences the consumed diet, because if not properly mixed, the meals consumed by the animal from the feed bunk may not contain the same concentrations of nutrients, or undesirable feed selection may be facilitated (Zebeli et al., 2012).

Oelberg (2011) suggested that the CV among the dietary portions in PSPS sieves 2 and 3, from 10 places along the feed bunk, must be lower than 5%, which would indicate that the diet was well homogenized. The mean CV of Sieve1 (CV Sieve1), Sieve2 (CV Sieve2), Sieve3 (CV Sieve3), and Bottom (CV Bottom) were 16.27, 5.36, 4.12, and 5.30, respectively. The average CV Sieve2 value was slightly higher than 5%, suggesting the potential for improvements in the mixing process; however, the CV of Sieve3 was adequate and lower than the recommended value. The range of CV (Min–Max) was very wide, showing minimum and maximum values of 2.4 and 14.3% for CV Sieve2, and 2.1

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and 8.1% for CV Sieve3, indicating that the homogeneity of the mixture varied widely among the monitored farms. In the current assessment, the average particle retention above Sieve1 was 19.23%, much higher than the recommended 2-8%. In situations in which the proportion of particles in Sieve1 is greater than 8%, the CV could be used to assess the quality of the mixture of long particles, since the relative values do not exhibit enough sensitivity. This behavior was also observed by Tayyab et al. (2018) when evaluating homogeneity of particles larger than 19 mm along the feed bunk. The CV of Sieve1 showed average values much higher than 5%, with minimum and maximum values of 7 and 59%.

The CV among the 10 samples collected along with different spots of the feed bunk was used to assess the homogeneity of the mixture, as previously described. According to Zebeli et al. (2012), the constancy of the mixture influences the diet consumed by cows in such a manner that when fed poorly mixed diets, the animals can easily sort out the long particles. The positive correlations between CV Sieve2 and NDFl and ADFl levels suggest that the higher the CV values, and consequently the worse the mixture homogeneity, the higher the selection against fiber by the animals. Such data corroborates that the CV Sieve2 value is useful for assessing the quality of the TMR mixture.

Several factors influence the quality of the mixture, including the duration of mixing after the last ingredient has been loaded, the loading order of the ingredients, and the final total weight as the proportion of the mixer total capacity (Oelberg, 2011; Zebeli et al., 2012). Among the 20 farms monitored, 5% had a mixing time after adding the last ingredient below 3 min, 40% above 5 min, and only 55% between 3 and 5 min.

According to Heinrichs et al. (1999), uniform diets are obtained after 3 to 5 min of mixing after adding the last ingredient. Longer mixing periods can cause an excessive reduction in particle size, decreasing peNDF content and increasing the risk of metabolic disorders. The recommended order of addition of ingredients to the mixing wagon is hay or haylage, followed by minerals and concentrates, corn silage, and finally liquid feeds (whey or water). In this way, hays and haylages, which usually have the highest particle size, would have their size reduced by the mixing wagon during mixing, which could benefit the mixing efficiency and improve the consistency of the diet (Oelberg, 2011; Zebeli et al., 2012; Almeida et al., 2013; Schingoethe, 2017). In the current study, only 55% of the 20 evaluated farms followed this recommendation.

Wagon overloading and underloading may also compromise the mixing efficiency. Costa et al. (2019) demonstrated that, in addition to compromising the homogeneity of the diet, the underloading of the mixer also affected the accuracy between the formulated and the offered diet. The recommendation is to fill to a maximum of 60-80% of its loading capacity to achieve optimal mixtures (Barmore, 2002). Among the 20 monitored mixers, 60% had a total load below 60%, 15% above 80%, and only 25% between the ideal 60-80%.

The positive correlations between %Sieve 1 and MPS with ADFo content suggest that as the proportion of long particles in the diet increases, ADF content also increases, probably because the long particles usually come from forage with high amounts of cellulose and lignin. The negative correlation between %Sieve 2 and DMo and the positive correlation between %Bottom and DMo suggest that the higher the proportion of long particles in the diet, the lower the DMo level. This may be due to the increase in forage in the diet, which consequently increases the proportion of long particles. These ingredients have lower DM levels than the concentrates, and therefore, at higher proportions, contribute significantly to reducing the final DM content of TMR.

This same correlation could explain the finding of lower DMo than DMf levels, as during ingredient loading, higher amounts of forage than required can be accidentally loaded into the mixer wagon, thereby increasing their proportion in the diet. The positive correlation between %Bottom and CPo and the negative correlations between MPS and CPo and between %Sieve 1+2 and CPo clearly show that diets with a lower proportion of long particles (>8 mm), and probably with a higher proportion of concentrates, typically have higher CP concentrations.

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5. Conclusions

There are important variations between the formulated, offered, and apparently consumed diets in the monitored herds, due to several factors related to diet management and forage processing. In most cases, the particle size distribution is outside the recommended values, especially in the case of long particles from forage. This leads to a correlation between the physical variables of the offered diet and the chemical composition of the apparently consumed diet, in which the high proportions of the total mixed ration retained in the sieves modify the composition of leftovers, increasing the remaining fiber content. The homogeneity of the total mixed ration also has a wide variation among farms, but with opportunities for improvement mainly in the management of the mixers. This homogeneity also influences the apparently consumed diet by facilitating the selection process when diets have low mixing quality, demonstrating the importance of monitoring homogeneity.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Conceptualization: J.H. Carneiro, J.F. Santos and R. Almeida. Data curation: J.H. Carneiro, J.F. Santos and R. Almeida. Formal analysis: J.H. Carneiro and R. Almeida. Funding acquisition: J.H. Carneiro, J.F. Santos and R. Almeida. Investigation: J.H. Carneiro, J.F. Santos and R. Almeida. Methodology: J.H. Carneiro, J.F. Santos and R. Almeida. Project administration: J.H. Carneiro, J.F. Santos and R. Almeida. Resources: J.H. Carneiro and R. Almeida. Software: J.H. Carneiro and R. Almeida. Supervision: J.H. Carneiro, J.F. Santos and R. Almeida. Validation: J.H. Carneiro and R. Almeida. Visualization: J.H. Carneiro, J.F. Santos and R. Almeida. Writing-original draft: J.H. Carneiro and R. Almeida. Writing-review & editing: J.H. Carneiro and R. Almeida.

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