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The effect of the calibration of the spiral feeder and the type of feed pellets on the precision of its dosing

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Abstract. When feeding dairy cows, there is a need for precise dosing of concentrate feed. The quality of the feed dosing process is influenced by the physical properties of the feed material and the accuracy of the feeder calibration. The aim of the study was to investigate the influence of the accuracy of calibration of the spiral feeder and the type of granulated feed on the precision of dosing feed material at the feeding station. The study used a feeding station intended for feeding cattle, equipped with a spiral feeder with a feed rates of up to 1 kg min^{-1}. Three types of feed material with different granule diameters were used for the tests. The characteristics of the feed pellets included their bulk density, diameter and length of the pellets. In the study, the accuracy of the feeder calibration was related to the number of feed mass measurements obtained in the calibration procedure. Options for three and six mass measurements were included. The tests were performed for two feed rates, i.e. 0.3 and 0.4 kg min^{-1}. In order to determine the accuracy of feed dosing by the spiral feeder, the dosing accuracy index was calculated. The research results were subjected to statistical analysis. A statistically significant impact of calibration on the accuracy of feed dosing was found. In the study, increasing the diameter of the granules was accompanied by an increase in the accuracy of its dosing.

Key words: dosing accuracy, feeder calibration, feeding station, granulated feed properties, mechanical engineering.

INTRODUCTION

Nowadays, dairy farmers who want to achieve high financial profits must carefully analyze the costs of milk production (Luik-Lindsaar et al., 2019; Leola et al., 2021). The largest costs of dairy production include the costs of animal feeding (Šenfelde & Kairiša, 2018; Andrighetto et al., 2023). Milk production efficiency depends on a properly selected animal housing and feeding system (Cielava et al., 2017; Gaworski et al., 2018). Currently used automatic feeding systems for cows and calves ensure the proper physical structure of the ration and synchronization of protein and energy supply for rumen microorganisms. They thus ensure good feed utilization and reduce animal stress

(Šenfelde & Kairiša, 2018; Herbut et al., 2019) and promote their appropriate body condition (Gołębiewski, 2017; Van Os et al., 2019; Chlebowski et al. 2020a).

The basic devices in automatic cattle feeding systems are feeding stations installed in barns and milking robots (Saliņš et al., 2014; Soonberg et al., 2018; Vaculík & Smejtková, 2019), which should ensure precise delivery of concentrate feed to animals. Precise feeding of cows ensures balanced digestion and increases animal production efficiency (Vegricht & Šimon, 2016). It also has a positive effect on metabolism in the rumen, therefore reducing the risk of ruminal acidosis and other digestive disorders. At feeding stations, feed is distributed to cows individually in the amount they need (Soonberg et al., 2018; Solonscikov et al., 2021). This allows for the reduction of feed losses while providing the appropriate amount of concentrate for cows at different levels of milk production (Vaculík & Smejtková, 2019). As a result of identifying cows at the feeding station, sorting cows according to nutritional needs is not necessary (Šenfelde & Kairiša, 2018). At the same feeding station, different doses of concentrate feed can be delivered at one time, from several hundred grams to several kilograms.

Various dosing devices (feeders) intended for feed in the form of meals, granules and liquid feed additives may be installed at feeding stations. Feeders are characterized by different designs of working elements and operating efficiency. Both the design of feeders and the physical properties of feed may affect the quality and accuracy of dosing concentrate feed to animals, which is important in order to save feed consumption. The most frequently used concentrate feeds in cattle feeding are granulated feeds. Feed pellets are characterized by various physical properties (humidity, bulk density, geometric dimensions and others), which affect the process of moving the material in feeders and the accuracy of their dosing (Chlebowski et al., 2018). Feeding stations with feeders enable full mechanization and automation of work including storage, transport and direct feeding of feed material.

An important aspect when feeding animals using feeding station is the calibration of its feeders (Porter, 2017; Chlebowski et al., 2020b). Calibration is a process of adjusting the amount of feed dispensed by the feeder to the given feed doses to animals. There is a special calibration procedure in the feeding station control system, which involves activating the feeder for a specific period of time. Then, the measured value of the mass of feed dispensed by the feeder is entered into the system. During calibration, doubts arise as to how many times the weight measurement should be performed, taking into account that there are feeds with different physical properties. In practice, farmers sometimes perform this measurement only once and then enter the obtained sample weight value into the system. The instructions for use of feeding stations suggest that the weight measurement should be repeated three times and the average value of the measurement should be entered into the feed distribution system (Instruction Book, 2006). Other options of feeding systems include automatic calibrations, which involve six repetitions of measuring the mass of samples, with three subsequent repetitions being performed at full feed rates and the remaining three at a different feed rates (Instruction Book, 2010). The calibration process of feeders installed in feeding stations consists in the fact that after bringing the transponder (intended only for calibration) close to the transponder reader, the feeder performs a certain number of revolutions. Then the collected portion of feed is weighed. The procedure is repeated and the average value of the weighed samples is entered into the system. The number of repetitions of sample mass measurement during calibration and the calculation of the average value from these measurements (calibration accuracy) may have a significant impact on the accuracy of feed dosing in feeding stations.

The aim of the research study was to determine the impact of the calibration accuracy of the spiral feeder and the type of granulated feed on the precision of its dosing in the feeding station.

MATERIALS AND METHODS

Laboratory research station

A DeLaval feeding station was used for the tests (Fig. 1). One to four feeders can be installed in one feeding station. These feeders are mounted inside the feeding station to the frame holder of the device. A volumetric spiral feeder (Fig. 1, a) intended for dispensing loose and granulated feed was used for the tests. The device dispenses feed as a result of the operation of an internal spiral driven by an electric motor.

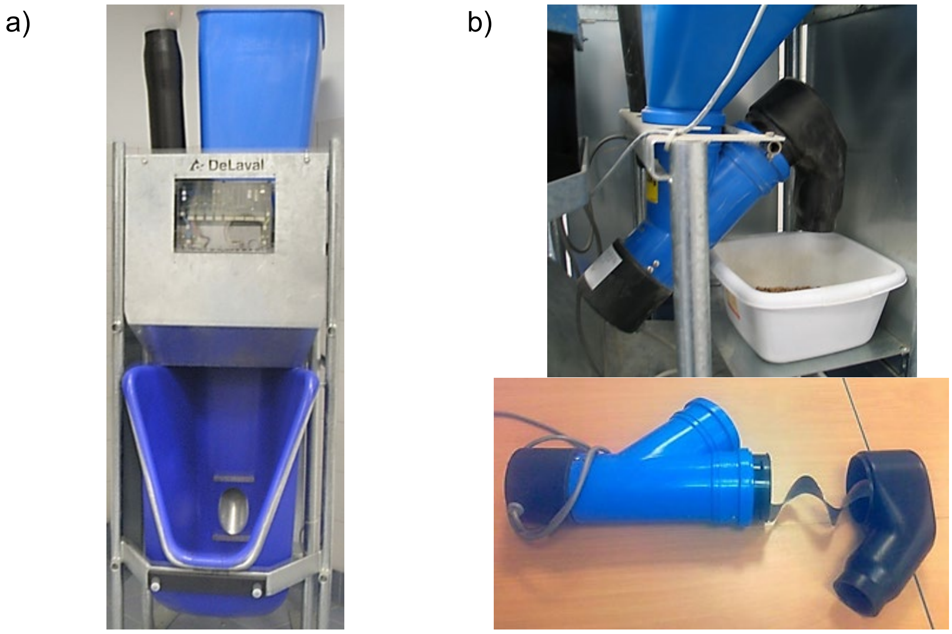

Figure 1. Test stand: a) feeding station, b) spiral feeder.

Characteristics of the tested material

Three concentrated feeds in the form of granules were used for the tests. The feeds varied in terms of the size of the granules (length and diameter) and the content of chemical ingredients. Detailed specifications of the feeds included in the study are presented in Table 1.

P2 feed had the highest protein content - 20%. The protein content in the remaining feeds (P1 and P3) was at a similar level of 17–18%. The P2 feed was the richest in fat and its content was 6%. The P3 feed had the lowest fat content.

Table 1. Characteristics of the tested granulated feed

Composition	Type of feed		
	P1 (Pszenmix)	P2 (Blatmilk Super 20)	P3 (Wimilk18)
Protein (%)	17	20	18
Fiber (%)	5	6	9
Fat (%)	3	6	2.2
Ash (%)	4.5	6	7.5
Photo of the feed, including scale			

Feed manufacturers did not specify the geometric dimensions of the granules. Due to their high importance in testing the accuracy of feeding concentrate feed, measurements were carried out to determine the length and diameter of granules for each type of feed.

Geometric dimensions of granules

The dimensions of the granules were found using an electronic caliper. To carry out the measurements, five random samples with a size of 100 granules were taken for each of the three types of feed. Measurements were made with an accuracy of 0.01 mm.

Granule moisture

The moisture content of the granules was determined using a laboratory dryer type SLW 115 TOP+. Three samples of each feed weighing 10 g were prepared. Previously, the granulate was ground on a laboratory grinder. The samples were dried for three hours at 130 °C. After completing the drying process, the samples were weighed. A WLC 1/10.X2 scale with an accuracy of 0.01 g was used to measure the weight of the samples.

Feed moisture was determined based on the following formula:

$$W = \frac{m_1 - m_2}{m_1} 100\% \tag{1}$$

where m_1 – mass of feed before drying, g; m_2 – mass of feed after drying, g.

Bulk weight

The bulk density of the feed pellets was determined in five repetitions by weighing the samples with an accuracy of 0.1 g:

$$\rho_g = \frac{m - m_p}{V} \tag{2}$$

where ρ_g – bulk density of granulated fodder, kg m^{-3}; m – mass of container with granulated fodder, kg; m_p – mass of container, kg; V – volume of container, m^3.

Testing the accuracy of feeding

The accuracy of dispensing concentrate feed was tested at the DeLaval feeding station (Fig. 1). The station was equipped with a concentrate feed feeder. The feeding station was controlled by a computer with a feeding program. The computer made it possible to change the device's operating parameters and record data.

The calibration value was defined in the study. The calibration value is the average mass obtained with a specific number of repetitions in the calibration mode. The calibration mode included a 3-time measurement of the sample mass (K3), a 6-time measurement of the sample mass (K6) and a 9-time measurement of the sample mass (K9). The calibration mode thus defined the number of repetitions performed to find the average sample mass. Three types of feed were used in the research: P1, P2, P3. The tests were carried out at two feed rates: C1 = 0.3 kg min^{-1} and C2 = 0.4 kg min^{-1}. The feed rates of the feeder was selected based on the feeding station service manual (Instruction Book, 2006).

Calibration of the feeder means that after bringing a specific transponder (intended only for calibration) closer to the transponder reader, the feeder performs a certain number of revolutions for 60 seconds. Then the portion received from the feeder is weighed. The procedure was repeated three, six and nine times for one of the tested feeds (P1). Average values from measurements of weighed samples were entered into the system. For feed P2 and P3, the feeder was calibrated only for three repetitions of the mass measurement (K3) and six repetitions (K6).

To determine the accuracy of dosing feed pellets, the dosing accuracy coefficient (3) was calculated. Pellet dosing tests consisted of weighing the mass of feed pellets dispensed once by the device and comparing the obtained results with the values indicated in the animal feeding system (1000 g). Measurements were performed in five repetitions for each type of feed pellet.

$$D_a = \frac{|x_r - x_p|}{x_r} 100\% \tag{3}$$

where D_a – dosing accuracy, %; x_r – indicated values in the feeding system, g; x_p – mass of weighed tested sample, g.

The analysis of the study results also included a comparison of the coefficient of variation (CV), which was calculated based on the following formula (Sheskin, 2000):

$$CV = \frac{\hat{s}}{\overline{X}} \tag{4}$$

where CV – coefficient of variation; $\hat{s}$ – standard deviation (SD); X – mean value.

Results were statistically analyzed using Statistica v.13 software (StatSoft Polska. Cracow. Poland).

RESULTS AND DISCUSSION

Feed moisture

A summary of the average moisture value of each feed is presented in Table 2. The P3 feed had the highest average moisture - 9.3%. The average moisture value for P1 feed was the lowest and amounted to 8.6%. For feed P2, the average moisture content was 8.9%.

Table 2. Moisture content of granules, including mean value, standard deviation (SD) and coefficient of variation (CV)

Type of feed	Mean (%)	SD (%)	CV
P1	8.6	0.21	0.024
P2	8.9	0.33	0.037
P3	9.3	0.24	0.026

Geometric dimensions of granules

The average geometric dimensions (length, diameter) of granules for each of the three feeds are presented in Table 3. The obtained values confirmed the differences in the size of granules of individual feeds. In terms of diameter, feed P1 had the largest granules (8.5 mm). Feed pellets P2 and P3 had similar diameters, their dimensions were 5.6 mm and 4.2 mm, respectively. The P3 feed was characterized by the longest granule length - its granules had an average length of 13.6 mm. The average length of the P2 feed pellets was the smallest and was approximately 12 mm. The average length of the P1 feed pellets was 12.7 mm.

Table 3. Geometric dimensions of feed granules: P1, P2 and P3

Type of feed	N	Length (mm)				
		Mean	Min	Max	SD	CV
P1	100	12.7	6.9	20.1	3.26	0.257
P2	100	11.9	5.6	17.1	2.18	0.183
P3	100	13.6	6.0	21.8	3.51	0.258
		Diameter (mm)				
P1	100	8.5	8.1	8.8	0.16	0.019
P2	100	5.6	5.3	6.6	0.13	0.024
P3	100	4.2	3.4	4.5	0.12	0.029

Based on the data in Table 3 and the one-dimensional significance test (Table 4), the hypotheses about the equality of variances for the diameter and length of the pellets for the three feeds can be rejected. It follows that the type of feed affects the diameter and length of the granules.

Table 4. Results of the analysis of variance covering the three types of pelleted feed included in the study, for two variables, i.e. diameter (in mm) and length (in mm) of the feed material

Factor	Sum of squares	Degrees of freedom	Mean square	F-ratio	*P*-value
	Diameter				
Type of feed	933.54	2	466.77	23,221.4	< 0.0001
Error	5.97	297	0.02	-	-
	Length				
Type of feed	136.03	2	60.01	7.35	0.0008
Error	2749.42	297	9.26	-	-

Bulk density

The results of the bulk density test of feed are presented in Table 5. The average bulk density of P1 feed was the lowest and amounted to 608.2 kg m^{-3}. The P3 feed had the highest average bulk mass, its value was 685.8 kg m^{-3}. The average bulk weight of the P2 feed was 661.6 kg m^{-3}. Small coefficients of variation indicate little variation in bulk weight for individual types of feed.

Table 5. Bulk density of granules, including mean value, standard deviation (SD) and coefficient of variation (CV)

Type of feed	Mean (%)	SD (%)	CV
P1	608.2	5.64	0.009
P2	661.6	4.21	0.006
P3	685.8	3.61	0.005

Accuracy of feed dosing in the feeding station

At the beginning of the research, the accuracy of dosing P1 granules was tested only for one repetition of the mass measurement during calibration of the feeder and the dosing accuracy (D_a) was calculated. As a result of this test, the average value of the D_a index obtained from five repetitions for the P1 feed was over 4%. Then, dosing accuracy tests were carried out with calibration performed for three repetitions of sample mass measurement, six repetitions and nine repetitions. Each time, the calibration value was entered into the feed supply system as the average value of the sample weight. The results were subjected to statistical analysis (Table 6), which indicated that there was no significant impact of the calibration method (repeating the sample weight measurement during calibration of the feeder) on the dosing accuracy for P1 feed.

Table 6. Results of the analysis of variance covering the accuracy of dosing of granulated feed P1 for three calibration modes (K3, K6 and K9)

Factor	Sum of squares	Degrees of freedom	Mean square	F-ratio	*P*-value
Calibration mode	3.63	2	1.81	1.30	0.2885
Error	37.60	27	1.39	-	-

Fig. 2 shows the influence of the type of calibration (K) on dosing accuracy. There are significant differences in dosing accuracy for three repetitions (K3) of sample mass measurement during calibration and six repetitions (K6). Minimal differences were observed between the K6 and K9 calibrations. These results provided the basis for rejecting the K9 calibration for P2 and P3 feeds in subsequent studies.

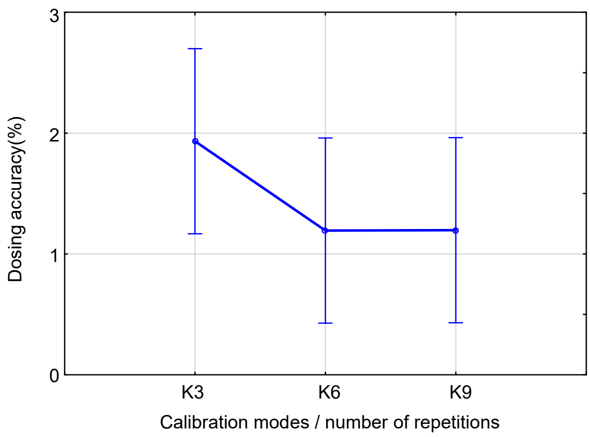

Figure 2. Comparison of the dosing accuracy of P1 granulated feed for three calibration modes (K3, K6 and K9).

Based on the results of the Kolmogorov-Smirnov (K-S) test, it was concluded that for dosing accuracy there is no basis to reject the H0 hypothesis about normal distributions for this parameter. The critical significance level was greater than 0.1. However, based on the results of Levene's tests, it can be concluded that for the dosing accuracy there is no basis to reject the H0 hypothesis about the homogeneity of variance, because the critical value of the significance level was 0.31 with the assumed limit value of 0.05. The variables (criterion parameters) were independent and random. Taking into account that the samples were random and the test results with a normal distribution of the variable and homogeneity of variance, it can be concluded that the conditions for conducting an analysis of variance were met.

The results of the analysis of variance for dosing accuracy with respect to the type of granulate P1, P2, P3, as well as K3 and K6 calibration and C1 and C2 feed rates are presented in Table 7. It was found that the calibration accuracy (which depends - based on the results of the research study - on the number of repetitions of the mass measurement) has a significant impact on dosing accuracy. The proof of the significance of this factor is the value of the Fisher-Snedecor F tests (11.69) and the low value of the critical significance level of 0.0012. The remaining factors did not have a statistically significant impact on the dosing quality, as evidenced by the low values of the Fisher-Snedecor F tests (for the type of feed - 1.65, for dosing efficiency - 0.44), also the values of the critical level of significance for these factors reached values below the assumed level significance $\alpha = 0.05$. Analyzing Fig. 3, a tendency of increasing feed dosing inaccuracies was noticed for feed pellets with a smaller diameter and higher bulk density (P2 and P3 feed).

Table 7. Results of the analysis of variance covering the dosing accuracy for the criterion of granulate type (type of feed: P1, P2 and P3), calibration mode (K3 and K6) and feed rates (0.3 and 0.4 kg min^{-1})

Factor	Sum of squares	Degrees of freedom	Mean square	F-ratio	*P*-value
Type of feed	3.89	2	1.94	1.65	0.2006
Calibration mode	13.74	1	13.74	11.69	0.0012
Feed rates	0,55	1	0.52	0.44	0.5098
Error	64.61	55	1.17	-	-

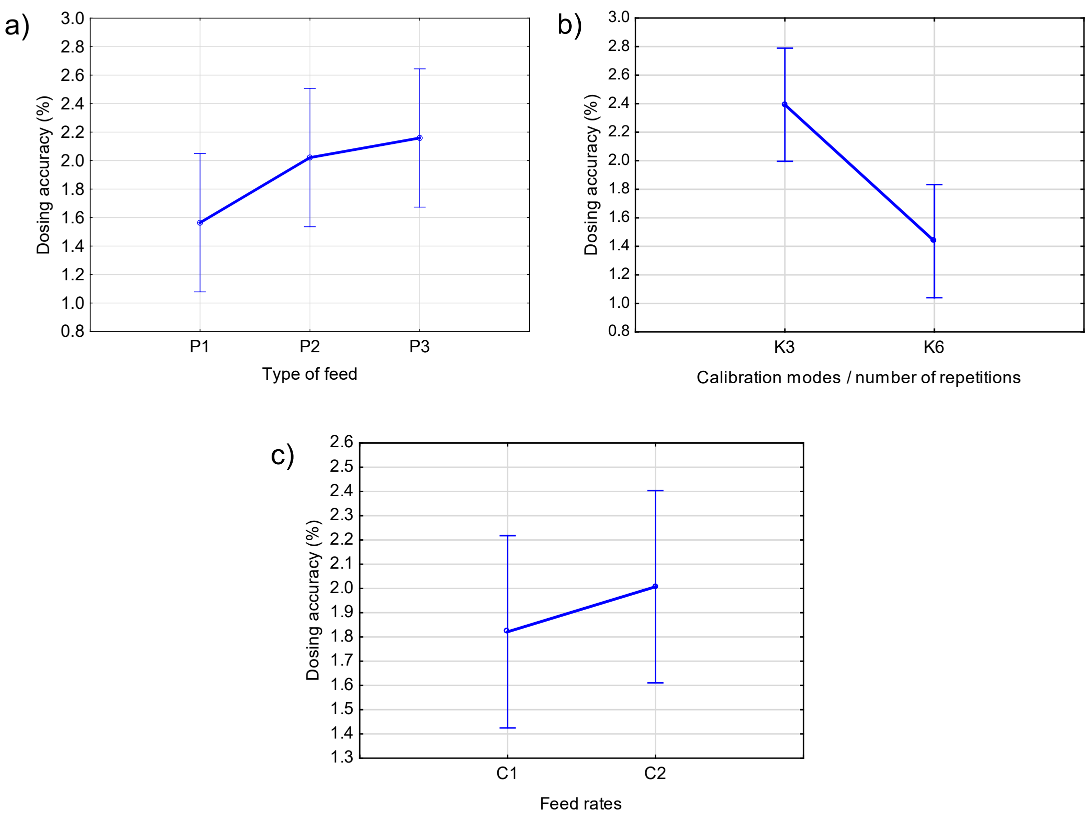

Figure 3. The effect of grouping factors on dosing accuracy for: feed type (a), calibration modes (b), feed rates (c).

The research results confirm the influence of feed properties on its movement in transport and dosing devices. An opposite tendency in changing the accuracy of granulate dosing was noticed for variable bulk densities of the granules compared to the results of research on the influence of granulate moisture on the accuracy of its dosing

(Chlebowski et al., 2018). It should be noted that the change in bulk density depended on the water saturation of the granulate and its swelling. Taking into account the obtained research results, subsequent studies should take into account other feed properties, e.g. angle of internal friction, cohesion (Stasiak et al., 2019), coefficients of sliding friction (Stasiak et al., 2020), which may affect dosing quality. No significant differences in dosing accuracy were observed when changing the granulate feed rates (Fig. 3, c). In subsequent studies, tests should be carried out for the entire range of feed rates from 0 to 1 kg min^{-1}.

Table 8. Duncan test results of average dosing accuracy values for calibration

Level of factor	Size	Mean dosing accuracy (%)	Homogeneous groups	
	Calibration mode, K			
K3	55	2.39	×	
K6	55	1.44		×

To confirm the influence of calibration accuracy on the accuracy of granulate dosing at the feeding station, the Duncan test was performed (Table 8). Two homogeneous groups were obtained, with a difference in accuracy of approximately 1% in favour of the K6 calibration.

CONCLUSIONS

1. The highest accuracy of dosing feed pellets at the feeding station, below 1%, was achieved for P1 pellets (Pszenmix). The greatest inaccuracy in dosing feed pellets at the feeding station during the tests was 5.5%.
2. Statistical analysis showed a significant impact of calibration accuracy, depending on the number of repetitions of mass measurement during calibration, on the accuracy of feed dosing in the feeding station.
3. The feeding station calibration process requires that sample weight measurements be repeated more than three times. Increasing the number of repetitions of measuring the weight of feed samples to six times during feeder calibration can increase the accuracy of the feeder in a feeding station by approximately 1%.
4. The statistical analysis shows that the type of feed and feed rates do not have a statistically significant impact on the accuracy of feeding at the feeding station.
5. The results of the research study provide an inspiration to continue experiments with other groups of animal feeds, including concentrates with a structure other than granules.

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