Particle size distribution in commercial pig compound feeds in Switzerland: survey and methodological considerations

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Partikelgrösse in kommerziellen Schweinefuttermischungen in der Schweiz: Erhebung und methodische Überlegungen

Das Ausmass der Zerkleinerung von Schweinefutter wird als ein möglicher prädisponierender Faktor für Magengeschwüre angesehen. Für Schweinefutter wurden verschiedene Empfehlungen zur Partikelgrösse veröffentlicht. Wir haben 51 verschiedene handelsübliche Mischfuttermittel für Schweine (38 Mehle, 13 Pellets/Granulate) einer Trocken – und/oder Nass-Siebanalyse unterzogen. Die Menge an Partikeln, die das feinste Sieb passierten (oder löslich waren), wurde durch die Differenz zu der vor dem Sieben gewogenen Gesamttrockenmasse abgeschätzt. Die mittlere Partikelgrösse wurde basierend auf Mittelwert des Gewichtes von dem im Sieb zurückgehaltenen Materials (MPS_{sieves}) unter Berücksichtigung dieses verlorenen Materials (MPS_{total}) berechnet. Die Trocken-Siebanalyse der Mischungen ergab MPS_{Siebe} von 0,58–2,90 mm und MP_{Stotal} von 0,58–2,89 mm; nur 0,02 bis 2,71 % der Trockenmasse passierten alle Siebe. Die Nass-Siebanalyse aller Mehle und Pellets ergab ähnliche MPS_{Siebe} von 0,63–1,66 mm, aber signifikant niedrigere MPS_{total} von 0,26–1,04 mm; zwischen 35 und 66 % der Trockenmasse wurden nicht auf den Sieben zurückgehalten. Pellets hatten im Vergleich zu den Fütterungsmehlen eine kleinere MPS und einen höheren Anteil an Partikeln, die alle Siebe passierten. Je nach verwendeter Referenz entsprachen maximal 26 % der Fütterungsmehle den Empfehlungen für die Partikelgrösse von Schweinefutter. Unabhängig der konsultierten Referenzliteratur erfüllte keine der pelletierten Futtermittel diese Kriterien. Die Nass-Siebung sollte als Standardanalyse angesehen werden, da bei der Trocken-Siebung sehr feine Partikel, die an grösseren Partikeln anhaften, möglicherweise nicht separat erfasst werden, sondern fälschlicherweise zu einem grösseren Partikelgewicht beitragen. Zusätzlich sollte die MPS-Berechnung den Materialverlust durch das feinste Sieb berücksichtigen. Weiter Untersuchungen sollten die Gründe abklären, warum Schweizer

Summary

The grinding intensity of pig feed is considered one potential predisposing factor for gastric ulcers, and a variety of particle size recommendations have been published for pig feeds. We subjected 51 different commercial compound feeds for pigs (38 meals, 13 pellets/granulates) to dry and/or wet sieve analysis. The amount of particles passing the finest sieve (or being soluble) was estimated by the difference to the total dry matter weighed prior to sieving. Mean particle size was calculated based on the weighted average of the material retained on the sieves (MPS_{sieves}), and additionally with accounting for this lost material (MPS_{total}). Dry sieve analysis of the meals yielded MPS_{sieves} of 0,58–2,90 mm and MPS_{total} of 0,58–2,89 mm; only 0,02 to 2,71 % of the dry matter passed all sieves. Wet sieve analysis of all meals and pellets yielded similar MPS_{sieves} of 0,63–1,66 mm, but dramatically lower MPS_{total} of 0,26–1,04 mm; between 35 and 66 % of the dry matter was not retained on the sieves. Pellets had smaller MPS, and a higher proportion of particles passing all sieves than meals. Depending on the reference used, a maximum of 26 % of meals conformed to recommendations for pig feed particle size. None of the pelleted feeds met these criteria, irrespective of the source consulted for the recommendation. Wet sieving should be considered the standard analysis, because in dry sieving, very fine particles adhering to larger particles may not be registered separately but contribute erroneously to larger particle weight. In addition, the MPS calculation should account for material lost through the finest sieve. Reasons why Swiss pig feed does not meet particle size recommendations should be further investigated.

Keywords: Diet, ulcer, stomach health, prevention, grinding

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Schweinefutter die Empfehlungen zur Partikelgrösse nicht erfüllen.

Schlüsselwörter: Diät, Magengeschwür, Magengesundheit, Vorbeugung, Zerkleinerung

Introduction

Ulcers of the *Pars oesophagea* of the porcine stomach have a high prevalence in fattening pigs, a phenomenon recently also confirmed in Switzerland.[10] To our knowledge, gastric ulcers in pigs are not considered a danger to food safety, but a major impairment of animal welfare. While various factors may be responsible for the development of ulcers, such as *Helicobacter* infection, generic stress, feeding management, diet ingredients, and general husbandry, the fineness of the particles in the feed is particularly important.[5] A high proportion of fine particles is linked with ulcer occurrence, whereas a high proportion of coarser particles has a protective effect.[18,23,27,28] This is commonly explained by the effect on the stomach contents: stomach contents of pigs fed finely ground diets are of a more liquid consistency, and these stomachs empty at a faster rate. Both phenomena make retrograde movement of gastric acid from the fundus to the *Pars oesophagea* more likely, a site of the stomach which is devoid of mucous-producing glands and hence susceptible to acidic damage.[18]

The chosen degree of grinding intensity for pig feeds has traditionally been described as a trade-off, with finer particles being better digestible thus favouring cost efficiency, but this at the expense of stomach health.[23,27,28] However, there is also evidence that body weight gain and feed conversion efficiency are not necessarily maximised at lower particle size.[14,18] Apart from a protective effect against gastric ulcers, feed of a coarser grind has also been found to be protective against the population of the digestive tract with undesirable bacteria such as *Salmonella*.[1,17,21]

Various recommendations for the particle size distribution in pig feeds have been published (Table 1). However, some of these recommendations do not specify how the corresponding measurement should be made. While a fractionation of particle sizes in a feed is typically done by sieve analysis, the results will vary distinctively depending on whether sieving is done dry (using a tower of sieves that are shaken) or wet (using the same tower with the addition of water, and after dissolving the feed in water).[3,16,26] The choice of the method is often justified by the conformation of the feed to be investigated: whereas feed in meal form can be analysed either way, pelleted feed (as whole pellets or as crumbles) can only be sieved after dissolution of the compacted material in water, and hence by wet sieving. Wet sieving has also been considered to more closely resemble the functional relevance of particle size distribution in the digestive tract, which is a moist environment.[16]

Other factors than dry or wet sieving that may lead to variation of results between different analyses relate to the mesh sizes of the sieves used, whether shaking of the sieve column is also applied during wet sieving, how the

Table 1: Recommended thresholds for the particle size distribution in pig feed for a prevention of health problems (mainly gastric ulcers) from various sources.

Source	Particle size	Recommended % of total DM weight		
		dry sieving	unspecified method	wet sieving
Coenen (1998)[3]	> 1 mm	> 10 %		> 10 %
	< 0,2 mm			< 35–40 %
Ulbrich et al. (2004)[20]	> 2 mm		5–10 %	
	1–2 mm		30–35 %	
	0,5–1 mm		30–40 %	
	< 0,5 mm		< 25 %	
Heinritzi et al. (2006)[9]	> 1 mm		20–25 %	
Grosse Liesner et al. (2009)[8]	< 0,4 mm			< 29 %
Wolf et al. (2010)[26]	> 1 mm		15–20 %	
	< 0,2 mm		< 20 %	
Kamphues et al. (2014)[13]	> 1,5–2 mm	> 5 %		> 5 %
	< 0,2 mm	< 40 %		< 50 %

water is applied to the sieve column during wet sieving (sprayed, or with pressure), and whether the fraction of material passing the finest sieve is accounted for. When expressing results of the sieve analysis as mean particle size (MPS), the method of calculating that measure from sieve results will also affect the numerical magnitude.[6,16,25] While variation in the used mesh sizes can be accounted for when calculating the MPS by choosing only data for comparable sieves between studies,[6] the determination of the fraction passing the finest sieve requires particular attention. Even if this fraction is quantified, the respective studies often do not explain in the methods how this is achieved,[e.g. 8,17,26] and sometimes this fraction is not mentioned at all.[e.g. 16] In theory, the material passing this sieve could be retained (in the case of wet sieving, catching all the fluid that passes through the sieve column) and quantified by further methods. The intensive dilution of this fraction requires, however, special efforts should the dry matter (DM) passing all sieves be quantified. Therefore, this fraction is usually quantified by exactly weighing the DM amounts of feed used for sieve analysis and those recovered on the individual sieves. The lost fraction can then be calculated by subtraction of the other fractions from the amount of DM used.[6] It has been suggested that measures of MPS will be more representative if this fraction is also taken into account, for example by setting some (very small) default particle size for it.[25] Indeed, in case this fraction made up a substantial proportion of the feed, any MPS that is calculated without accounting for it would represent a massive overestimation.

Generally, when applying both dry and wet sieving to the same feed sample, the wet sieving method yields a higher proportion of very fine particles, and sometimes a higher proportion of very large particles, with a concomitant reduction of the proportion of medium-sized particles.[3,26] The following explanations have been put forward:[25] During the soaking that usually precedes wet sieving, some particles might swell and hence be retained on larger sieves. Soluble particles (e.g., salt grains) will dissolve in water and not be retained on the sieves, adding to the fraction calculated by subtraction. And the wet sieving process has been suspected to result in a mechanical particle size reduction when particles are pressed against the sieve meshes,[25] although empirical evidence is lacking. Yet, another possibly very important aspect has been little emphasized to our knowledge – the effect of adhesive forces that bind very fine particles to relatively larger particles (illustrated in Figure 1). These forces are unlikely to be overcome by dry shaking, whereas this is accomplished by washing. Depending on which other particles the fine particles adhere to in the feed and hence also during dry sieving, they will add to the weight of that other particle fraction and distort the results.

In the present study, our main aim was to document the particle size distribution in commercially available pig feed in Switzerland as a first step towards a putative adjustment of feeding practices to enhance gastrointestinal health in pigs. In addition, we aimed to test the effect of dry versus wet sieving, illustrate the effect of pelleting on particle size, and explore the contribution of soluble versus very fine particles to the fraction passing the finest sieve.

Material and methods

Feed samples

Sixteen different Swiss pig feed manufacturers (representing 4 of the 7 *grandes régions* of Switzerland) provided samples of 51 different compound feeds, of which 25 were designated for fattening pigs (grower and finisher diets) and 26 for adult sows; 38 of the feeds were in meal form, and 13 came as pellets or granulate. In order to assess the effect of pelleting on the particle size distribution of feed, pellets of a diameter of 3 and 6 mm were produced from two of the meals using a small-scale pelleting machine (RP18, Ecokraft AG, Deggendorf, Germany). In pellet production 5 % of water were added.

Analyses

Approximately 100 g of each feed was weighed into a tared aluminium dish and dried at 103°C for at least 24 h till constant weight. After cooling in a desiccator, the samples were weighed again, and the dry matter (DM) content (%) was calculated as dry weight (g) / initial weight (g) × 100.

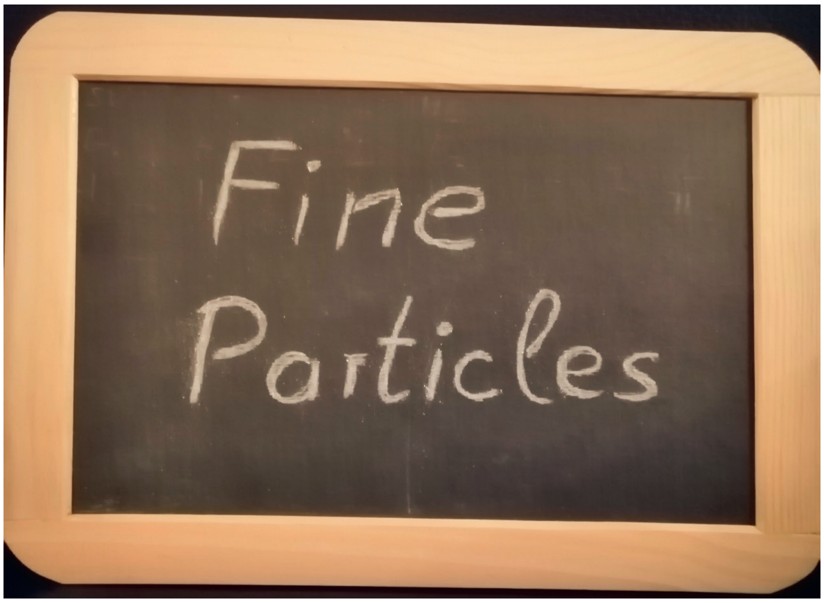

Figure 1: Adhesive forces keeping very fine particles (here chalk) connected to a large particle (black-board) even after a period of intense dry shaking. The small particles will be separated from the large particle by the application of water. Example following Visser.[22]

The particle size distribution was analysed via sieving using a Retsch device (AS200 digit, Retsch, Haan, Germany) at a vibration amplitude of 50 to 60, and a column of ten sieves with linear dimensions of quadratic holes of 8, 4, 2, 1, 0,5, 0,25, 0,125, 0,063, 0,040 and 0,025 mm. Between the three finest sieves, aeration rings were positioned in case of wet sieving, to support water flow through the sieves by preventing a stagnant air column that can develop between two sieves if water is spread consistently across the upper sieve. Each analysis was performed in duplicate. The exact amount of feed (in g original matter) submitted to sieve analysis was documented. After dry or wet sieving, the material retained on each sieve was transferred manually to tared petri dishes, which were subsequently dried at 103°C to constant weight, and weighed again after cooling to room temperature in a desiccator.

Meals were assessed by dry sieving, and meals as well as pellets/granulates by wet sieving. For dry sieving, approx. 40 to 50 g of the original material was directly applied to the top sieve, and the sieve column was exposed to vibrations for 8 min. Material passing the finest sieve was lost. For wet sieving, approx. 25 g of original material was put into a beaker with 500 mL of water and was gently stirred with a magnetic stirrer at room temperature overnight. The beaker was emptied (with repeated flushing) on the top sieve; subsequently, the sieve column was closed with a lid connected to a hose, and sieving took place for 8 min. During the first 7 min, water at a flow of approx. 2 L/min was applied as a spray to the top of the sieve column. The last minute served for the water to flow out of the column. Water and the material passing the finest sieve – either due to extremely fine particle size or solubility in the water – were discarded.

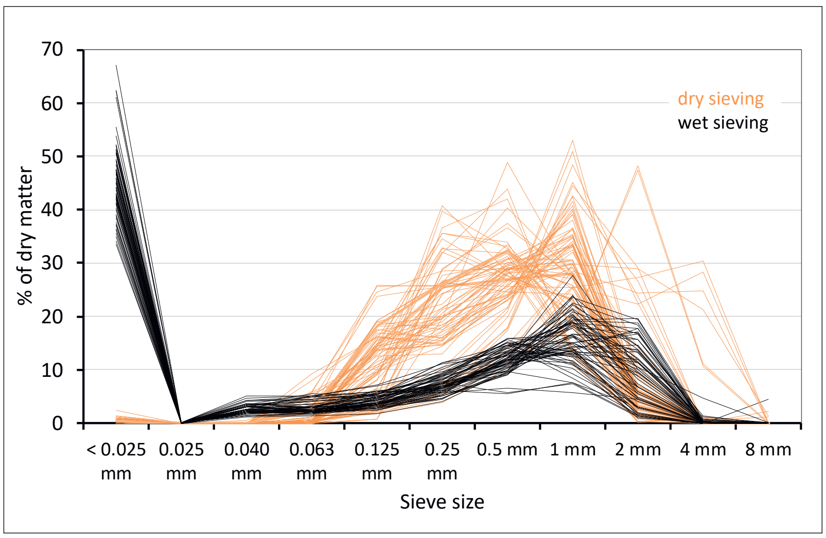

Figure 2: Percentage of total dry matter retained on the sieves with indicated mesh sizes (linear dimensions of quadratic holes) in commercially available pig feed in meal form (each line represent a sieve analysis of a sample). The fraction of < 0,025 mm was determined as the difference of the sum of dry matter retained on all sieves from the total dry matter amount used for the analysis.

In an additional duplicate run carried out with a single meal, the water passing through the sieve column in 5 min (approx. 10 L) was caught in a canister. This material was subjected to a series of filtration, centrifugation and evaporation steps: it was filtered through a tared glass filter containing washed quartz sand, celite and cotton wool, which was re-weighed after drying at 103°C and cooling in a desiccator. The filtrate was reduced in volume by evaporation by boiling to approx. 3,5 L, and the resulting suspension was centrifuged at 11,5 g in a 5810R (Eppendorf, Hamburg, Germany). After disposing the supernatant, the centrifugate was again reduced by boiling to approx. 300 mL. This fluid was sucked through a tared filter with a 0,22 µm pore sized hydrophilic polyethersulphone membrane by a vacuum pump; the filter was weighed again after drying at 103°C and cooling in a desiccator. Up to this step, material of a particle size between 25 and 0,22 µm was retained. The remaining difference to the weighed-in DM was assumed to represent soluble material in the feed. Although the coefficient of variation was low for the duplicate analysis of particulate matter between 20 and 0,22 µm (5,7 %) and for the solutes (3,2 %), the method was not validated, and must be considered exploratory.

Calculations

Using the amount of original matter submitted to sieve analysis, and the DM concentration of the respective feed, the total amount of DM submitted to sieve analysis was calculated. The difference between this amount and the sum or the DM retained on all sieves was interpreted as non-retained DM that passed through the finest sieve. Material retained and not retained on sieves was expressed as a percentage of the total DM subjected to sieve analysis. The mean particle size (MPS) was calculated following the dMEAN approach of Fritz et al.[6] With sieves ordered from size $S(1)$ (minimum) up to size $S(n)$ (maximum pore size), and the proportion $p(i)$ of particles retained at the size $S(i)$, dMEAN is then defined as:

$$dMEAN = \sum_{i=1}^{n} p(i) * \frac{S(i+1) + S(i)}{2}$$

With this approach it is assumed that the average size of a particle retained on a sieve is the mean between the mesh size of the sieve it is retained on and the preceding (upper) sieve in the column. For material retained on the largest sieve, the upper size is measured manually as the observed maximum length of this fraction contains a relevant amount of material larger than the size of this sieve (which was not the case in the present study). The MPS calculated in this way depends on the set of sieves used (for the calculation)[24] and the basis on which the proportion *p(i)* is expressed. Following the frequently applied practice, the MPS was first expressed on the basis of all material retained on the sieves; the resulting MPS is called MPS_{sieves} in the present study. In a second approach, also the material that passed the finest sieve was considered. Then *p(i)* was expressed as the proportion of the total DM subjected to the sieve analysis. In this case, a (very low) average particle size is assumed for the fraction that passed the finest sieve in the calculation. The choice of this assumed magnitude depends on the mesh size of the smallest sieve used.[25] In the present study, this material represented particles that passed a 25 µm sieve. Hence, choosing 12,5 µm as the theoretical size of this particle fraction was the logical option (MPS_{total}). In this context, it should be noted that for the effect of a difference between MPS_{total} and MPS_{sieves}, it is not the choice of the theoretical size of the particles passing the finest sieve that is the decisive step, but the expression of the proportion of particles on the basis of all material (incl. that passing the finest sieve). By necessity, MPS_{total} is always smaller than MPS_{sieves}.

Statistical analyses

Statistical analyses were performed in R.[19] Because most data were not normally distributed according to the Shapiro-Wilk test, nonparametric comparisons were performed throughout. For the comparison of sieve results from dry versus wet sieving of meals, a paired test (Wilcoxon signed-rank test) was used; for the comparisons between meals versus pellets, and fattening pig versus adult sow feeds, a non-paired test (Mann-Whitney U test) was used. The significance level was set to 0,05. Results are displayed as range (minimum-maximum), median, and quartiles. Because the median is the measure corresponding to the nonparametric statistics, significance is indicated in the tables at this measure.

Results

Dry versus wet sieving

There was a distinct difference in the particle size distribution depending on whether meals were sieved dry or wet (Figure 2). The two methods differed significantly in the percentage retained on all sieves, except of the material retained on the 2 mm and 4 mm sieves (Table 2). In particular, wet sieving yielded a drastically higher percentages of very fine particles (≤ 0,063 mm), and correspondingly lower percentages of medium-sized particles. Notably, particles in the size range of 0,025 mm had a very low percentage with both sieving methods (Figure 2, Table 2). Generally, meals met the recommendations (Table 1) regarding the percentage of particles ≥ 1 mm, irrespective of the sieving method. While all the meals met the recommendation of having less than 40 %

Table 2: Comparison of sieve results for commercially available pig feeds in meal form (n=38) from dry and wet sieving, and in pelleted form (n=13, wet sieving only)

Method		% of dry matter retained on sieve (mm)														Mean particle size (mm)	
		<0,025	0,025	0,04	0,063	0,125	0,25	0,5	1	2	4	8	< 0,4	< 0,2	≥ 1	MPS_{sieves}	MPS_{total}
Meals																	
dry	min	0,02	0,00	0,00	0,00	0,78	4,92	11,88	11,63	0,21	0,02	0,00	7,87	1,61	12,66	0,58	0,58
	quart	0,37	0,00	0,00	0,19	4,44	12,98	22,72	27,22	2,61	0,09	0,00	25,05	6,76	31,81	0,89	0,88
	med	0,48^{A}	0,00^{A}	0,01^{A}	0,55^{A}	11,11^{A}	17,77^{A}	26,91^{A}	33,18^{A}	5,18	0,15	0,00^{A}	32,76^{A}	13,12^{A}	38,92^{A}	0,97	0,96^{A}
	quart	0,85	0,01	0,01	2,86	15,49	24,74	29,77	37,21	10,00	0,29	0,01	39,04	17,83	49,77	1,19	1,19
	max	2,71	0,02	0,26	8,70	25,11	35,64	44,65	51,91	47,84	26,14	1,13	58,40	31,27	79,42	2,90	2,89
wet	min	34,88	0,00	1,22	1,43	2,34	4,29	6,06	6,60	1,17	0,00	0,00	47,69	42,43	8,83	0,71	0,26
	quart	41,94	0,02	2,03	2,15	3,46	6,01	10,68	13,18	5,34	0,02	0,00	55,95	50,23	18,74	0,97	0,52
	med	45,14^{BC}	0,02^{B}	2,39^{B}	2,71^{BC}	3,75^{BC}	7,09^{B}	12,00^{B}	15,88^{BC}	10,08^{C}	0,08	0,02^{B}	61,38^{BC}	53,82^{BC}	25,75^{BC}	1,23^{C}	0,68^{BC}
	quart	48,59	0,04	2,96	3,27	4,90	8,36	13,55	18,89	13,36	0,18	0,05	67,51	59,32	32,46	1,48	0,87
	max	64,66	0,09	4,73	5,11	7,04	10,89	15,90	25,75	20,27	2,41	2,26	83,44	77,44	42,06	1,66	1,04
Pellets																	
wet	min	40,46	0,00	1,80	2,17	3,47	6,79	8,06	6,70	0,39	0,00	0,01	61,28	51,14	7,14	0,63	0,26
	quart	46,53	0,00	2,58	3,13	4,83	7,62	11,24	9,52	2,56	0,01	0,02	65,32	57,23	12,85	0,81	0,36
	med	49,11^{D}	0,02	3,00	3,61^{D}	5,42^{D}	8,91^{D}	12,41	13,56^{D}	4,11^{D}	0,04	0,02	72,40^{D}	62,17^{D}	18,06^{D}	0,94^{D}	0,47^{D}
	quart	53,37	0,02	3,37	4,55	5,75	10,13	12,73	14,59	5,44	0,11	0,05	75,40	66,98	21,83	1,05	0,60
	max	59,37	0,11	3,54	5,22	7,05	10,40	15,11	20,80	9,62	0,20	0,09	80,45	72,30	26,33	1,20	0,64

Min, minimum; max, maximum; med, median; quart, upper and lower quartile ^{A,B}meals dry vs wet, ^{C,D}meals vs pellets: medians within a column differ significantly (p<0.05) of DM on sieves < 0,2 mm, only 10 (26 %) met the recommendation of having less than 25 % of DM on sieves < 0,5 mm at dry sieving. By contrast, at wet sieving, no meal met the recommendation of having less than 25 % of DM at < 0,5 mm or less than 29 % of DM at < 0,4 mm. The most recent recommendation of having less than 50 % of DM at < 0,2 mm at wet sieving was only met by 8 (22 %) of the meals. The MPS_{total} was significantly different between the methods; this was not the case with MPS_{sieves} (Table 2). For the two meals from each of which two pellets of different diameter were produced, the difference between dry and wet sieving was evident as well (Figure 3). In the single meal where the fraction not retained in the sieves was analysed in detail, 52 % of all DM passed the finest sieve. Thereof, 32 % were particulate matter in the size range of 0,025 to 0,00022 mm (25 to 0,22 µm), and 20 % of the material was soluble.

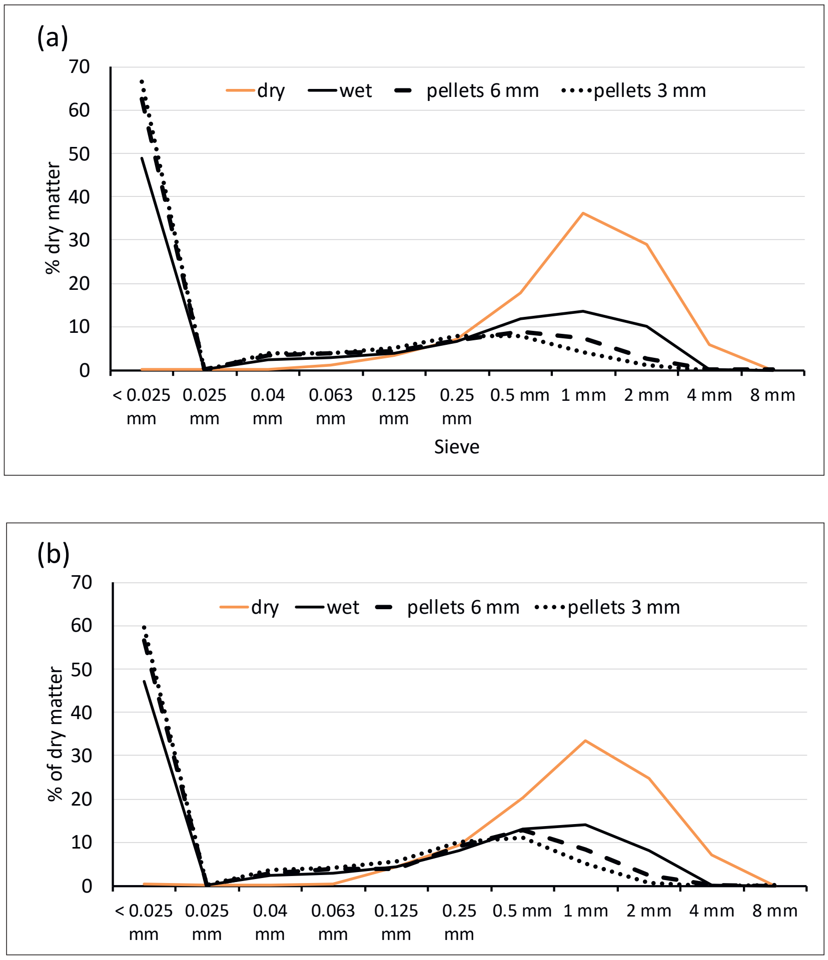

Figure 3: Percentage of total dry matter retained on the sieves with the mesh sizes indicated (linear dimensions of quadratic holes) in two pig feeds (a: fattening diet; b: breeding diet) available as meals. Each meal was analysed by dry sieving (orange line) or wet sieving (black line), and by wet sieving after pellets of a diameter of 6 mm (interrupted line) or 3 mm (dotted line) had been pro-duced from the meal. The fraction of < 0,025 mm was determined as the difference of the sum of dry matter retained on all sieves from the total dry matter used for analysis.

Meals versus pellets

Generally, pelleted feeds had a higher proportion of finer particles than meals, and correspondingly also a smaller MPS, irrespective of the method of MPS calculation (Table 2). The 0,5 mm sieve size was the turning point; on this sieve, a similar percentage of DM was retained for meals and pellets. Pellets generally met the recommendations regarding the percentage of particles ≥ 1 mm. No pellet sample met the recommendations of having less than 25 % of DM at < 0,5 mm, less than 29 % of DM at < 0,4 mm, or less than 50 % of DM at < 0,2 mm. Pelleting of two meals was found to reduce the percentage of larger particles, with the smaller pellet diameter showing the larger reduction (Figure 3).

Differences between feeds designed for fattening pigs and adult sows

To exclude an effect of the feed manufacturing method, this comparison was only performed with the meals. There was no significant differences between feed designations in either the MPS_{sieves} (fattening pigs: median 1,19 mm, range 0,71–1,63 mm; adult sows: 1,25 mm, 0,76–1,66 mm) or the MPS_{total} (fattening pigs: median 0,65 mm, range 0,26–1,01 mm; adult sows: 0,73 mm, 0,37–1,04 mm). The percentage of DM not retained on the sieves was slightly, but significantly higher in feeds for fattening pigs (47,8 %, 36,7–64,7 %) compared to that for adult sows (44,0 %, 34,9–51,2 %; $P < 0,05$).

Discussion

The present study corroborates well-known differences between dry and wet sieving, and in the particle size distribution between pig feeds sold in meal versus pelleted form. Most particularly, the results indicate that the majority of pig feeds analysed, and hence likely a large proportion of the commercially available pig feed in Switzerland, does not meet the recommendations concerning particle size distribution, but contains a proportion of very fine particles that is too high.

Methodological aspects: dry versus wet sieving

Systematic differences between dry and wet sieving results have been previously reported in the literature.[3,4,16,26] While dry sieving is considered convenient due to the lower labour effort required, several disadvantages of the method have been mentioned. These include the possibility that electrostatic forces might make particles stick to the sieves, and the agglomeration especially of fatty particles.[16] Finally, dry sieving evidently cannot be applied to pelleted or granulated feed, so for comparable results, all feeds should be subjected to wet sieving. Our results illustrate a severe disadvantage of dry sieving that may make analysed pig feeds in meal confection appear closer to particle size recommendations than they actually are: very fine particles most likely adhere to larger ones due to adhesion forces,[22] thus increasing the weight percentage of larger, and decreasing the weight percentage of finer particles. Additionally, dry sieving probably represents biological processes in the digestive tract to a lesser extent (where, for example, soluble material will dissolve).[16] To conclude, results from dry and wet sieving cannot be compared, and wet sieving, though more laborious, should be considered the standard for future approaches.

Comparison to literature data and recommendations

When compared to other literature data,[2,26] the proportion of particles < 0,5 or < 0,2 mm measured in the Swiss pig feed samples appears high. One reason for the difference could be that the cited studies did not use vibration as part of the wet sieve analysis (or did not report it). Even the kind of vibration used can influence the result of wet sieve analyses.[25] Nevertheless, results of the same magnitude as ours were also reported by wet sieving without[8,18] and with[17] vibration. While a standardization of vibration settings would be desirable, we do not think that variation in these settings during wet sieving are of a magnitude that changes the judgement of a series of feed samples in a relevant way.

The secondary particle size reduction effect of pelleting has been well described in the literature.[26] Compared to meals, the advantages of a pelleted diet include an improved palatability, an increased starch digestibility, and less wastage.[15] When the advantages of a pelleted diet shall be used, this size-reducing effect should be considered when choosing the grinding fineness of the ingredients.

The observation that compound feeds for adult sows had a somewhat coarser particle structure than feed for fattening pigs has been made previously.[26] Most likely, reasons for this are not in stage-specific aims of grinding intensity, but in differences in ingredients that lead to an unintended change in particle size structure. More detailed studies on changes of particle size distribution during the production process, including measurements of the particle size of individual ingredients at different production steps, would help to understand these observations.

Material passing the finest sieve

Recommendations regarding the percentage of coarse particles in pig feeds were met in the present study, and therefore may not be the primary concern. Additional measures, for example the requisite to provide structured material with a minimum particle length as prescribed in Switzerland by the IPS label,[12] will help to increase the supply of coarse ingesta that is likely protective against gastric ulcers.[10] In this context, especially grass silage seems to be advantageous, more so than long chopped straw, due to the higher intake from the silage.[11] With respect to commercially designed pig feed, it is particularly the very fine particle fraction that is of relevance.

In wet sieve analyses of feeds, the fraction of material passing the finest sieve is often very large. Frequently, sieve sets used for wet sieving have a lowest mesh size of 0,5–0,2 mm (Table 1), and the very fine particles are summarized correspondingly as < 0,5 or < 0,2 mm. This fraction comprises soluble parts of the feed, tentatively estimated in the present study to make up as much as 20 %. Solubles are likely not only composed of mineral salts, but also of sugars and other soluble carbohydrates that are part of the feed ingredients. Because soluble substances will not aid in the compaction and stratification of stomach contents, but contribute to fluid stomach contents, including them in the very fine fraction when evaluating pig feeds with respect to gastric ulcers appears justified. This view is also supported by the finding that feeding a finely ground diet had the same effect on gastric ulcer prevalence regardless of whether it was fed dry (i.e., with soluble material only going into solution at the point of ingestion by the animals) or in liquid form (i.e., soluble material had time to dissolve before feeding).[18]

In the present study, the lowest mesh size was 0,025 mm. Very little material was retained on the corresponding sieve, but a substantial percentage of the feed material was insoluble and had a lower particle size – tentatively estimated in the present study to account for 30 %. Although microbes are in the respective size range (10 to 1 µm),[7] we do not suggest that microbes are represented particularly in this fraction. Rather, considering the increase in this fraction after pelleting (Figure 3), we suggest that these very fine particles are the result of mechanical processes in feed production. This also matches the general observation that pelleting reduces the bacterial load of a feed, due to the sterilizing effect of heat during pelleting, and the lower surface of the final product available for microbial colonisation.[17] Still, commercial pelleted feeds had a higher percentage of very fine particles in our study. While speculations on how to achieve a reduction in the very fine particle fraction is beyond the scope of our study, we hope our findings are an incentive to feed producers to try changes in their production line to lower the percentage of very fine particles in pig compound feeds. In this context, sampling and sieve analysis of ingredients at every stage of the production process (e.g., before and after grinding) would help identify critical steps. Detailed analyses, possibly including optical and chemical analyses of the respective material, could further help to identify the origin and relevance of the very fine particles. Because recommendations on particle size distributions in feed are not given on the basis of MPS, but on the basis of thresholds for a specific particle size, the choice of MPS appears of secondary relevance in such future studies. Nevertheless, we suggest that for a realistic evaluation, whenever some form of MPS is indicated, the MPS_{total} should also be included.

Conclusion

Out of 51 investigated samples of commercially available pig feed in Switzerland, none of the 13 pelleted diets, and at best 22% of the 38 meal diets, were complying with the recommendations about the maximum percentage of very fine particles. While no direct link to the occurrence of gastric ulcers can be made in the present study, these observations lead to the intuitive hypothesis that this high prevalence of fine dietary particles is one of the contributing factors to the high prevalence of gastric ulcers in Swiss pigs recently determined.[10] Ways to reduce the fine particle load in pig feed should be explored.

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Taille des particules dans les aliments composés commerciaux pour porcs en Suisse : enquête et considérations méthodologiques

L'intensité de broyage des aliments pour porcs est considérée comme un facteur potentiel de prédisposition aux ulcères gastriques et diverses recommandations sur la taille des particules ont été publiées pour les aliments pour porcs. Nous avons soumis 51 différents aliments composés commerciaux pour porcs (38 farines, 13 pellets/granulés) à une analyse par tamisage à sec et/ou humide. La quantité de particules passant le tamis le plus fin (ou étant solubles) a été estimée par la différence avec la matière sèche totale pesée avant le tamisage. La taille moyenne des particules a été calculée sur la base des moyennes pondérées du matériel retenu sur les tamis (MPSsieves) en tenant compte en plus du matériel perdu (MPStotal). L'analyse des mélanges par tamisage à sec a donné des MPSsieves de 0,58–2,90 mm et des MPStotal de 0,58–2,89 mm ; seule 0,02 à 2,71 % de la matière sèche a passé tous les tamis. L'analyse par tamisage humide de toutes les farines et des granulés a donné des MPSsieves similaires de 0,63–1,66 mm, mais des MPStotal nettement inférieurs de 0,26–1,04 mm ; entre 35 et 66 % de la matière sèche n'a pas été retenue sur les tamis. Les granulés présentaient des MPS plus faibles et une proportion plus élevée de particules passant par tous les tamis que les farines. Selon la référence utilisée, un maximum de 26 % des farines étaient conformes aux recommandations relatives à la taille des particules des aliments pour porcs. Aucun des aliments granulés ne

Dimensioni granulometriche nelle miscele commerciali di mangimi per suini in Svizzera: indagine e considerazioni metodologiche

Il grado di sminuzzamento dei mangimi per suini è considerato un possibile fattore predisponente alle ulcere gastriche e sono state pubblicate diverse raccomandazioni sulla dimensione dei granuli per i mangimi dei suini. Abbiamo sottoposto 51 diverse miscele di mangimi commerciali per suini (38 farine, 13 pellet/granuli) all'analisi del setaccio a secco e/o a umido. La quantità di particelle che hanno superato il setaccio più fine (o che erano solubili) è stata stimata dalla differenza rispetto alla sostanza secca totale pesata prima della setacciatura. La dimensione media delle particelle (DMP) è stata calcolata in base al peso medio del materiale trattenuto nel setaccio (DMPsetacci) tenendo conto del materiale perso (DMPtotale). L'analisi dei setacci a secco delle miscele ha mostrato una DMPsetacci di 0,58-2,90 mm e una DMPtotale di 0,58–2,89 mm; solo lo 0,02–2,71 % della sostanza secca ha superato tutti i setacci. L'analisi al setaccio umido di tutte le farine e dei pellet ha mostrato una DMPsetacci analoghi di 0,63-1,66 mm, ma con una DMPtotale significativamente inferiore di 0,26–1,04 mm; tra il 35 e il 66 % della sostanza secca non è stata trattenuta dai setacci. I pellet presentavano una DMP inferiore e una percentuale maggiore di particelle che passavano tutti i setacci rispetto alle farine. A seconda del riferimento utilizzato, un massimo del 26 % delle farine soddisfaceva le raccomandazioni sulla dimensione delle particelle nei manrépondait à ces critères, quelle que soit la source consultée pour la recommandation. Le tamisage humide devrait être considéré comme l'analyse standard car, dans le tamisage sec, les particules très fines adhérant à des particules plus grosses peuvent ne pas être enregistrées séparément mais contribuer de manière erronée au poids des particules plus grosses. En outre, le calcul du MPS devrait tenir compte de la matière perdue par le tamis le plus fin. Les raisons pour lesquelles les aliments pour porcs suisses ne répondent pas aux recommandations sur la taille des particules devraient être étudiées plus en détail.

Mots clés: Régime alimentaire, ulcère gastrique, santé gastrique, prévention, broyage

gimi per suini. Mentre, indipendentemente dalla letteratura di riferimento consultata, nessuno dei mangimi a pellet soddisfaceva le raccomandazioni. La setacciatura a umido deve essere considerata l'analisi standard, poiché la setacciatura a secco potrebbe non rilevare separatamente le particelle molto fini che aderiscono a quelle più grandi, ma che contribuiscono erroneamente a un peso maggiore delle particelle. Inoltre, il calcolo della DMP deve tenere conto della perdita di materiale attraverso il setaccio più fine. Ulteriori indagini dovrebbero chiarire le ragioni per cui i mangimi per suini svizzeri non soddisfano le raccomandazioni sulle dimensioni delle particelle.

Parole chiave: dieta, ulcera, salute dello stomaco, prevenzione, macinazione

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