Manipulating Particle Size to Impact Animal Performance

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Take-Home Message

Regardless of the species of concern, particle size reduction is a necessity in feed manufacturing. The reduction in particle size is important to both animal performance and further feed processing. In the past, grinding was considered a relatively simple exercise, and the biggest concern was the average particle size obtained. However, with improvements to equipment, new data on animal performance, and increased understanding of analysis techniques, it is prudent to consider particle size as something to be constantly manipulated in order to achieve maximum production and profitability.

Both hammermills and roller mills are used to reduce particle size, and each has its advantages. Furthermore, as equipment designs evolve, both are able to cross over somewhat into the areas typically dominated by the other. This provides manufacturers with increased flexibility, and improves the ability to make fine adjustments to target specific particle characteristics. However, the goal remains the same: to find the balance between processing costs and animal performance.

Animal performance can be greatly impacted through the manipulation of particle size. For swine, the finer the grind the better, and this is especially true where genetics have greatly reduced the likelihood of damage (e.g. ulcers) to the digestive system. Of course, pelleted and mash feeds have different rules, mostly due to flowability issues. For poultry, the most recent research demonstrates that the inclusion of coarse material (at least for broilers) is important for digestive function. This is leading to many interesting ideas on how particle size can be manipulated in order to encourage natural functions while also improving upon digestive efficiency.

Particle size analysis is a standard practice in many animal research labs. Unfortunately, the standard itself can be interpreted in ways that can make results inconsistent and non-comparable. Moving forward, it will be important to not only document the exact method used, but also to provide greater description of actual particle distribution.

Why We Manipulate Particle Size

Particle size reduction is one of the most investigated areas of feed manufacture. This is due to the fact that it is the oldest processing technique, and because it is the most commonly necessary manufacturing step. There are typically two reasons for reducing particle size, improved animal performance and to facilitate further feed processing. The impact on animal performance is determined by measuring production parameters, such as gain, final bodyweight, and feed efficiency. From a processing perspective, the variables of concern are product size and uniformity, energy consumption, and the impact on downstream processes, e.g. pelleting.

Concerning animal performance, grains, and occasionally other ingredients, are ground to improve consumption and nutrient digestion. Particle size reduction leads to an increase in total exposed surface area, and this means a greater interaction with digestive acids and enzymes. However, not all species react the same to changes in particle size. In fact, differences in animal age, production stage, and purpose (e.g. production of meat vs. offspring) have been shown to require different approaches. Additionally, as genetics are evaluated and improved, the impact of particle size reduction changes as well.

Concerning further processing, particle size reduction represents a significant portion of feed production costs. The smaller the grind, the more expensive the feed, and so it becomes important to understand the cost-benefit relationship for the animal being fed. Also, the degree and type of particle size reduction can impact feed flow, mixing, pelleting, and finished feed quality.

Recently, we have begun to look at grinding more as a manipulation of particle size. That is to say, it has become about more than grinding to a specified size in the most cost efficient way. Rather, we are looking at things like the inclusion of both coarse and fine particles in a single feed. Work is being done to look at the impact of grinding on non-grain ingredients, as well as on the grinding of the complete diet. And we are becoming more concerned with the specific distribution of particles, rather than just the average size and overall range.

Equipment

The equipment utilized typically falls into two categories: hammermills and roller mills. In the manufacture of feeds, the use of one or the other is typically dependent on the feed type being produced. Often, pelleted feeds will be manufactured using hammermill ground materials, while mash feeds depend on roller mills, as roller milled material typically exhibits superior flow characteristics. Roller mills typically provide a more uniform particle size distribution, while hammermills have the advantage when it comes to very fine grinding and the grinding of fibrous materials. It is also important to understand that not all grains are equal when it comes to grinding. This is true both across and within grain species. Kernel size, moisture content, and proximate fractions all play a part in particle size reduction. When it comes to particle size manipulation, both grinders have design elements which allow the producer to make changes to the grinding operation based on these variables, and in order to meet the nutritional and physical handling requirements of the finished feeds.

While the basic design of the hammermill has been similar for quite some time (free swinging hammers impacting grain until the particles are small enough to pass through a perforated screen), there are certain design elements that have much improved the equipment's efficiency and capability. The split-screen hammermill allows for much greater control over both particle size and distribution. As the particles within the grinding chamber contact the hammers they gain speed and begin to travel in a direction more parallel to the screen surface. When this occurs the particles "see" a reduced diameter of hole opening. The split-screen design allows us to use a slightly larger diameter hole on the up-side of hammer rotation, which leads to particles exiting the chamber more quickly. This means less attrition, which contributes to a more uniform particle size distribution, reduced heat buildup and moisture loss, and improved grinding throughput. Hammermills may be installed with variable frequency drives (VFDs), which allow for the control of rotating speed and therefore control of hammer tip speed. Slower tip speeds are more appropriate for coarse grinds, while faster speeds are better for fine grinds (Heimann, 2008). Having the ability to easily vary the tip speed, and thus more readily manipulate the particle size based on grain type, animal species, etc. is a significant advantage. Finally, all modern hammermill designs incorporate air-assist systems. These systems create a slight negative pressure on the outside of the screen surface, which helps to prevent screen blinding and reduces dust. This keeps the system operating a steady state, making it easier to fine-tune the process and achieve the particle characteristics desired.

The roller mill originated in the flour milling industry, and was adopted by feed manufacturers to perform the relatively simple task of cracking grains. Since its early use, the roller mill has evolved into a specialized piece of equipment that can be set up in multiple ways depending on the final product desired. Roller mills vary in number of roll pairs, e.g. single pair, two-high, and three-high machines. Single pair roller mills are typically used to crack grains, and are generally configured to grind one grain source. Two-high machines have the ability to crack multiple grain sources, or can be used to obtain a finer grind (Heimann, 2008). The three-high machine has been considered a specialty mill, used when a very fine product is required. Historically, the roller mill has been limited when very fine materials are desired; for these applications a hammermill was necessary. However, three-high (and potentially four-high) designs that are properly configured are now being considered where both fine grinding and product flowability are important. In addition to the numbers of roll pairs, roller mills can vary in roll corrugation and differential. These attributes add shear to the already present compressive grinding force, and can aid in both the degree and control of particle size reduction.

Process Flow

Process flow plays a significant role in the manipulation of particle size. In general, systems are considered to be either pre- or post-batch grinding. The most common domestic system is the pre-batch grinding system, where cereal grains are individually ground prior to mixing with other ingredients. This works well when only one or two cereal grains are being utilized, and/or when each has a dedicated grinding stream. In the post-batch system, multiple cereal grains and some other major ingredients are weighed, ground in batches, and then a final mixing step is performed, adding micro ingredients and liquids. This system is more typically found in regions of the world where the use of multiple cereals is required in a formulated feed, and is done to reduce the required processing time. Because a large portion of the ingredients are ground, there is a requirement for large equipment capable of grinding at the rate of batching and mixing.

The use of these two systems can lead to differences in both particle size and distribution. In the pre-grind system, only the grain fraction is ground, and so there will likely be a wider range of particle sizes in the mixed feed. In the post-grind system, where many of the major ingredients are ground, there is the opportunity to create a more uniformly sized mixed product. While this can have some positive impacts on pellet quality, the impact on animal performance is dependent on the response to the potentially finer grind of the non-grain major ingredients.

Further Processing

Animal performance is impacted by finished feed attributes, such as percentage of fines, and it is often assumed that finer grinding improves pellet durability. However, unless the difference in particle size is very large, research has shown that particle size may have less of an effect on pellet quality than expected. Stevens (1987) examined the effects of particle size of ground corn on pelleting, and found no effect on pellet durability. In this case, corn in the diet was ground to 1025, 795, and 550 microns, yielding PDI values of 89.9, 88.8, and 90.3, respectively. Supporting the theory that total diet particle size may have a greater impact than the particle size of the grain fraction only, Stark (1994) found that particle size of the overall diet significantly affected pellet durability. Corn/soy diets with particle sizes of 545 and 235 microns yielded PDI values of 97.3 and 98.5, respectively.

Robinson et al. (1962) stated that the "best recommendation…is to grind as fine as is necessary to make a quality pellet." And this seems to fit the general attitude today that grinding, while important, is not one of the most important changes to make in order to affect pelleting. This is true also because, as Behnke (2006) stated, "The effects [of particle size] are not the same under all conditions or for all rations. The operators must conduct their own research under their own operating conditions and on the feeds that they produce."

Animal Performance

The primary reason for particle size reduction is of course to improve animal performance. As discussed earlier, the degree to which grinding impacts the animal is dependent on species, age, and production type.

For most ruminants, only moderate particle size reduction is needed due to the unique form of digestion. This is why much of the particle size reduction for ruminants is done on-farm. Grains may be cracked or, through the use of specialized processes, steam flaked in order to improve consumption and digestion. Further particle size reduction is required for pelleted supplements and range cubes, but the size is usually driven more by processing requirements than by animal performance.

In swine, much of the manipulation of particle size has to do with whether the feed is fed as mash or pellets. Mash feeds must have ground materials with a particle size large and uniform enough to allow for consistent flow through feeders. This is why mash feed producers tend to favor roller mills. For pelleted feeds, producers grind as fine as is practicable in order to take advantage of the improved digestion made possible by increased exposed surface area. Many studies have focused on determining the appropriately fine particle size, and the following two references are well-cited examples.

Healy et al. (1994) evaluated the growth performance of pigs on a pelleted starter diet, where corn and sorghum were ground to 300, 500, 700, or 900 microns. Pigs fed corn tended to respond more to changes in particle size than those fed sorghum and from 0-14 days, gain and feed efficiency both showed linear improvement as particle size decreased. Overall, feed efficiency had a quadratic relationship with particle size, with maximum efficiency found at 500 microns. Wondra et al. (1995b) used a hammermill to grind corn to 400, 600, 800, and 1,000 microns and added it to diets fed to finishing pigs. A linear effect was observed, and reducing the particle size from 1,000 to 400 microns yielded an 8% improvement in feed efficiency.

Following up on these works, Paulk et al. (2011b) fed corn and sorghum diets to finishing pigs. The corn based diet acted as the control (corn was ground to 555 microns), while three sorghum based diets represented the treatments, with particle size ranging from 320 microns to 725 microns. Reducing the sorghum particle size improved feed efficiency and tended to improve carcass yield. In comparison with the corn based diet, regression analysis demonstrated that sorghum should be ground 40-50 microns finer in order to achieve a similar feeding value.

Particle size is not the only attribute of concern. Uniformity has also been evaluated to determine its impact on animal performance. Wondra et al. (1995a) ground corn using both a hammermill and a roller mill, and different particle uniformities were achieved. Results showed that more uniform particle distributions led to improvements in nutrient digestibility. Experiments have also been conducted to evaluate alternative grinding operations. Paulk et al. (2011a) added ground and cracked corn to a supplement pellet in order to determine the feasibility of reducing feed processing costs. It was determined that the process is likely not a viable option, unless it is used to control mortality (due to the reduction of digestive lesions) or meet production rates (by reducing the amount of feed that must pass through the pellet mill).

Some ongoing research has focused on the fine grinding of major feed ingredients in swine diets. This has applicability to the post-grind systems discussed previously, as well as potential implications for processors of co-products used in animal feeds. To this point, fine grinding of major feed ingredients has been shown to improve pellet quality, which could ultimately be a benefit, but otherwise has not improved swine performance.

In poultry, both mash and pelleted diets are used extensively, though they tend to separate along production-types, with broilers typically receiving pelleted diets, and breeders and layers typically receiving mash feeds. In the past, poultry producers have followed suit with their swine counterparts and ground cereal grains fine in order to enhance digestion. However, based on the functional differences between the avian and monogastric systems, recent work has focused on manipulating particle size in order to both improve digestion and promote the natural function of the digestive system.

Chewning et al. (2012) conducted an experiment where corn particle size was 270 and 570 microns, and diets were fed to broilers as mash and pellets. Smaller particle sizes led to improved feed efficiency in the mash diets, but there was no observed difference in the pelleted diets. The authors concluded that reduced particle size did not improve performance in a pelleted diet. Parsons et al. (2006) varied corn particle size among five treatments, ranging from 780 to 2,250 microns. Here, the increased particle size improved nutrient retention, though performance and energy metabolism decreased at average particle sizes above 1,000 microns. These two studies are examples of those demonstrating that fine grinding for broilers may not only be unnecessary, but may in fact be detrimental to performance.

Recently, research began to look into the inclusion of coarse material into the ration for broilers. The thought process is that coarse material could benefit digestion by allowing the gizzard to function as intended, and that the coarse material represents a cost savings at the feed mill. Clark et al. (2009) experimented with adding corn post pellet. Cracked corn was used to replace the ground corn fraction in the diet at rates of 0, 25, and 50%. Five treatments were created to evaluate a "step-up" program. Treatments included: 1) control (0% cracked corn throughout feeding), 2) 0% cracked corn (0 to 17 d) and 25% (18 to 41 d), 3) 0% cracked corn (0 to 17 d) and 50% (18 to 41 d), 4) 25% cracked corn (0 to 41 d), and 5) 50% cracked corn (0 to 41 d). Improvements in gain and feed efficiency demonstrated that up to 25% of the corn fraction could be replaced with cracked corn without limiting broiler performance. The upside to this practice is that the corn, removed from the diet, would not pass through the pellet mill, and would thus save pelleting time and cost. The downside is that most feed mills do not possess the ability to blend dry ingredients post pelleting.

With the above in mind, experiments have progressed in the direction of utilizing coarse corn within the complete pelleted diet. Xu et al. (2013) fed broilers one of two dietary treatments, where coarse corn made up 0 or 50% of the total dietary corn. Fine corn (hammermill ground to 270 microns) and coarse corn (roller mill ground to 1,150 microns) were blended to create the dietary treatments. All diets were pelleted. The inclusion of coarse corn led to improvements in bodyweight and feed efficiency, and also yielded lower litter moisture. Another component of this study was floor type, and birds on new wood chip litter showed similar effects even without coarse corn, suggesting litter consumption may have aided digestive function. Auttawong et al. (2013) also fed broilers one of two dietary treatments, where coarse corn made up 0 or 35% of the total dietary corn. Fine corn (hammermill ground to 260 microns) and coarse corn (roller mill ground to 1,080 microns) were blended to create the dietary treatments. All diets were pelleted. Birds were fed ad-libitum and on a time-limited basis. The inclusion of coarse corn improved feed efficiency when the birds were fed ad-libitum. Interestingly, when under feed restriction conditions, the coarse corn effect disappeared. This is thought to be due to the birds being more hungry, and that they consumed litter when feed was not available, which again likely aided gizzard function in a similar manner to coarse corn inclusion. These studies demonstrate the positive impact of coarse material on broiler performance. However, the time-limited feeding raises questions on the impact of coarse material in feed-restriction situations, such as in breeding and laying operations.

Lin et al. (2013) fed broiler breeders two mash diets from 24 weeks of age into production, one containing 0% coarse corn and the other containing 50% coarse corn. As is typical for breeders, birds were under a feed restriction. The fine corn diet increased production (egg mass and number), while the coarse corn led to smaller birds which began producing later, and were unable to produce at the same rate. It was concluded that the fine corn provided the necessary energy under the restricted feeding conditions. The combination of these studies are good examples of how particle size must be manipulated, even within a single genetic line, based on feeding practices and production requirements.

Similar to the work in swine, research has been done on the particle size of ingredients other than the main cereal grains. The difference with other ingredients is that wide ranges or multiple particle sizes are difficult to obtain. These co-product ingredients (soybean meal, DDGS, etc.) have a relatively uniform distribution based on their processing. Therefore, the material can be as coarse as it arrives, or ground finer, but little ground exists in between without significant process complexity. As an example of this work, Pacheco et al. (2013) obtained DDGS with a particle size of 700 microns. A representative fraction was ground to 350 microns, and both were used in diets fed to broilers. Birds fed 350 micron DDGS had greater bodyweight at 42 days of age, and in general performed better. However, birds fed 700 microns had greater gizzard weights, which has been typical in experimental treatments with coarse material. These results make for interesting discussion, as one could choose to grind a co-product finer in order to gain performance, or could search out a coarse co-product to influence gizzard function, and grind the cereal grain to the size most optimum for growth.

Testing Particle Size

A discussion of particle size manipulation cannot be had without touching on the issue of particle size analysis. The standard method for particle size analysis (ASAE S319) has existed in some form since the 1970's. It is based on the assumption that ground materials are represented by a logarithmic distribution, and reports size and distribution based on weight. The procedure utilizes standardized sieves which enable the separation of ground material into known fractions.

Unfortunately, the standard includes a number of options which may be utilized or not, and this can make comparisons of results difficult. Options include the type of sieve shaker used, the use of sieve agitators (brushes, balls, etc.), the use of a dispersion agent (flow agent), and the sieving time. We (Fahrenholz et al., 2010) reported on an experiment that evaluated how these options can impact the final results of a sieve analysis. It was found that changes in a single option could impact geometric mean diameter (d_{gw}) by as much as 100 microns, and geometric standard deviation (s_{gw}) by as much as 0.42. When options are used in specific combination, d_{gw} was shown to vary by 200 microns or more, and s_{gw} by more than 1.0. These results demonstrate the importance of using a consistent method for analysis, and ensuring that any data comparisons are based off the same methodology.

As far as which method is best, it is this author's opinion that whichever method yields the lowest d_{gw} and highest s_{gw} is the most accurate analysis. This is based on the assumption that no particle size reduction occurs during sieving, and that these results would represent the particles reaching the proper sieves. This is typically done by utilizing sieve agitators, a flow agent, and a 15 minute sieving time. As most published work regarding particle size only refers to using the standard method, it is worth considering that particle sizes reported are only relative to the method used.

Further, based on the information discussed, it is possible that d_{gw} and s_{gw} values are not the only values worth reporting. Especially in cases where coarse materials are introduced into the diet, it is likely important to consider and report actual fractions (e.g. % above __ screen) in order to fully understand and evaluate the distributions utilized.

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Notes