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FEED MANUFACTURING TECHNOLOGY: CURRENT ISSUES AND CHALLENGES

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Animal agriculture has been changing rapidly for the last two decades. One of the most significant changes has been in the area of feed requirements for optimum performance. Genetic improvements are placing constant pressure on feed manufacturers to produce quality feeds that match the increased requirements of improved breeds without creating additional physiological or health stress. Increased understanding of nutrition, the environmental impact on animal performance, and even philosophical differences between nutritionists have caused feed manufacturers to alter "business as usual." Additional factors, such as the increased demand for high value specialty feeds for pets, equine, aquaculture, ratites, early weaning diets for nursery pigs and the like, have contributed to the need for improved feed manufacturing techniques.

This paper will focus primarily on three areas of feed manufacturing that are under active research attention. These areas are:

1) Grain particle size and its effect on animal performance;
2) Feed (nutrient) uniformity and its effect on animal performance;
3) Pellet quality issues.

Additional topics briefly discussed will be in-line pellet moisture and quality control, hygienic treatment of finished feeds, odor control, and trends toward liquid ingredients.

Grain Particle Size and its Effect On Animal Performance

Grain is ground prior to mixing to increase surface area for improved rate of digestion, decreased segregation and mixing problems, and to facilitate further processes such as extrusion or pelleting. Extensive grinding requires more energy; however, even small improvements in feed efficiency will often justify the added cost (Ensminger, 1985).

A study to evaluate the effects of grain sorghum particle size on nutrient digestibility was conducted by Owsley et al. (1981). Using ileal cannulated pigs, they found that upper tract digestibilities of N, DM, GE, starch, and most amino acids were increased as particle size was reduced. Total tract digestibility trends were similar but the differences were not as great. For example, ileal starch digestion was 19% greater in pigs fed grain sorghum ground through a 3.2 mm screen vs. those fed a coarsely rolled grain sorghum. Total tract difference was only 3%. It is recognized that starch is fermented to VFA in the large intestine and absorbed by the pig (Argenzio and Southworth, 1975). However, synthesis of VFA into glucose is less efficient than release and absorption of glucose from starch in the small intestine (Black, 1971). It can then be argued that decreased particle size of grain is one technique useful in improving its utilization in growing-finishing pigs.

Reducing the particle size of barley by 14% (789µ vs. 676µ) improved ADG and G/F by 5% for starter pigs (Goodband and Hines, 1988). The finely ground barley gave G/F equal to that of grain sorghum ground to 753µ. They concluded that the nutritional value of barley could be improved more than grain sorghum by fine grinding.

Ohh et al. (1983) found improved G/F and DM, GE, and N digestibility when the particle size of corn and grain sorghum was reduced. Roller milling and hammermill grinding gave similar results. Wu (1985) found a response to fine grinding of corn in finishing pigs but not in weanling pigs.

Performance of pigs fed wheat may not be improved by extensive particle size reduction. Average daily gain and G/F were similar in starter pigs fed diets containing wheat ground to 860µ or 1710µ average particle size (Seerley et al., 1988). Growing pigs fed wheat ground to the same particle size were 8% more efficient than pigs fed diets with 1710µ wheat but ADG was not affected. Finishing pigs gained 9% slower and were 6% less efficient when fed diets with wheat ground to 860µ vs. 1710µ. These studies would indicate that optimum particle size of wheat increases for older pigs.

Fine grinding has been implicated in the development of ulcers in the esophageal region of pigs (Reimann et al., 1968; Hedde et al., 1985). This is still an area of active investigation. Cabrera et al. (1993) found that stomach morphology was negatively affected by fine grinding (<600µ) of corn and two grain sorghum genotypes; however, improved performance would likely make fine grinding an acceptable compromise. They also found a dramatic decrease in daily DM and N excretion as grain particle size was reduced.

Wondra et al. (1993) investigated the influence of mill type (hammermill vs. roller mill) on finishing pig performance and stomach morphology. Mill type did not affect growth performance, but pigs fed corn ground by a roller mill had greater digestibilities of DM, N and GE and excreted 18% less DM and 13% less N than pigs fed hammermill ground corn. Pigs fed the roller mill ground corn had slightly better ulcer scores than those fed hammermilled grain.

Information regarding the effect of grain particle size on broiler performance is limited. Reese et al. (1986) reported improved G/F for broilers fed diets with corn ground to 910µ vs. 1024µ but only when the diets were pelleted. The authors implied that uniformity of particle size might also affect broiler performance.

Healy et al. (1994) investigated the effect of particle size of corn and hard and soft grain sorghum on growth performance and nutrient utilization in broiler chicks. Starting with seven-day-old chicks, they conducted a 21-day growth assay using diets made from each grain ground to 900, 700, 500, or 300µ. Gains for day 0 to 7 were maximized at 500µ for corn, 700µ for the hard endosperm grain sorghum, and 300µ for the soft grain sorghum. Maximum G/F for corn and soft grain sorghum was 300µ and 500µ for hard grain sorghum. For days 0 to 21 gain was optimum for corn at 700µ, for hard grain sorghum at 500µ, and for soft grain sorghum at 300µ. The authors concluded that reduced particle size improved growth performance and that, if properly processed, grain sorghum has a nutritional value equal to corn.

The fineness of grind found to be optimum in the above investigation is much finer than typically found in the U.S. broiler industry. In general, hammermills are equipped with 10/64" (4 mm) or 12/64" (4.8 mm) screens, usually resulting in an average particle size in the 800µ to 1000µ range. An interesting finding in the Healy et al. (1994) study is that gizzard weights were less in chicks fed the 300µ treatment. It is apparent that if the organ is not utilized for its intended function, development can be inhibited. This may have a significant economic impact by reducing the proportion of lower value parts.

Current Issues - Grinding

There is a great deal of interest in evaluating roller mills as an alternative to hammermills. The largest feed mill in the world has but one small hammermill used to grind "overs" of the ground grain scalper. All other grinding is done with roller mills.

Some U.S. manufacturers are looking at the common European practice of post-mix grinding to improve pellet quality. In most cases, minor improvements are noted but at a substantial cost in energy and capital. A relatively new concept in mill design has been proposed by a large engineering firm (Ibberson, Minneapolis, MN). In effect, this is a hybrid between pre-grind and post-grind and allows management to select the operation of choice depending upon the operation and feed quality desired.

Air-assisted hammermill systems continue to gain acceptance. In addition to increasing throughput by up to 25%, moisture shrink and product temperature rise are substantially reduced.

A new hammermill design has been developed by Buhler, Inc. (Minneapolis, MN). The design is novel in that the shaft is vertical rather than horizontal. Screen changing is easily accomplished and particle uniformity and grinding efficiency is said to be improved over conventional hammermills.

Evaluating the effect of grind fineness on animal performance continues to be an active area of research. Much needs to be learned regarding other cereals as well as protein meal in this regard. It is known that fermentation rate is increased as particle size is reduced (for ruminants). Little is known of the effects of fine grinding on hindgut fermentation, as in horses.

Feed (Nutrient) Uniformity And Its Effect On Animal Performance

Mixing is considered to be one of the most critical and essential operations in feed manufacturing regardless of whether it's on-farm or in a commercial facility. Lack of proper mixing can lead to reduced diet uniformity, affecting not only animal performance but regulatory compliance as well.

Few feed manufacturers really know how their mixers are performing or what mix time is required for a given diet. An ongoing survey of commercial mixers found that over 50% did not meet the “de facto” industry standard of a coefficient of variation (CV) of less than 10% when using methionine and lysine as the tracer (Wicker and Poole, 1991). A survey of farm feed mixers found very similar results (Stark et al., 1991). In their study, 42% of the participants had CVs of less than 10%, 47% were between 10 and 20% CV, and 11% had CVs greater than 20%. Salt was used as the tracer in this study.

Even though the importance of diet uniformity is intuitive, there is very little credible research that relates diet uniformity to animal performance. Numerous authors have cited uniformity as one of the most important aspects in feed production (Beumer, 1991; Ensminger et al., 1991; Wilcox and Balding, 1986). However, credible animal studies relating factors such as mix time, diet uniformity, and ingredient segregation are not available in abundance. Duncan (1973) provided insight into the effect of ingredient nutrient variability on animal performance and quality control. If nutrient density is highly variable, it would have the same effect as nutrient variation because of poor mixing or segregation.

McCoy et al. (1994) conducted two experiments to investigate the effects of diet nonuniformity, caused by inadequate mixing, on the performance of broiler chicks. In both experiments, a common diet formulation was mixed for different times to represent poor, intermediate, and adequate uniformity. In the first study, only G/F was improved as diet uniformity increased. In the second experiment (a 28-day growth assay), improvements were noted in ADG, ADFI, and G/F as diet uniformity increased from poor to intermediate. No further enhanced performance was noted as diet uniformity was increased to adequate.

In a recent study, Traylor et al. (1994) examined the effect of mix time on diet uniformity and subsequent growth performance of nursery and finishing pigs. For Experiment 1, 120 weanling pigs were used in a 27-day growth assay. Treatments were mix times of 0, 0.5, 2.0, and 4.0 minutes for a Phase II nursery diet. They found that ADG improved by 49% and F/G was decreased by 16% as diet uniformity was increased. In the finishing pig study, 128 animals were fed from 124 lbs to 260 lbs final body weight. Treatments were the same (mix times) as used in the nursery study. Increasing mix time reduced diet variability (CV) from 54% to less than 10% but did not significantly affect ADG, ADFI, or F/G. However, pigs fed the most nonuniform diet had the poorest rates and efficiencies of gain.

Conclusions reached in both of these studies (McCoy et al., 1994; Traylor et al., 1994) were that body size and, therefore, daily food intake, of young animals is a critical aspect relating diet uniformity to animal performance. Older, more mature animals that consume larger meals and retain digesta longer are less sensitive to variation in diet uniformity than young animals.

Current Issues - Diet Uniformity

There is obviously a great deal of research needed to document more fully the level of uniformity needed to optimize performance of target animals. It is disturbing to contemplate the fact that the basis for all formulation, nutrition, and regulatory control is the assumption of nutrient or additive uniformity, yet very little real data exist to support this assumption.

There is a distinct possibility that regulatory agencies such as FDA/CVM will require that all mixers used to manufacture medicated feed will have to be validated as to blending ability and required mix time. At present, at least one Canadian province requires biannual testing of medicated feed mixers.

The recent introduction of short cycle mixers will have a great impact on mill design and operation. If the mixing cycle is reduced from 5-8 minutes to 1-3 minutes, it is obvious that other operations, such as hand weighment, batching, and liquid additions, will have to be streamlined. Management will become a greater challenge.

Perhaps the most needed item is the development of a dependable mixer testing procedure that is acceptable to both the industry and regulatory agencies. At present, there is no "standard" procedure available that meets the requirements of accuracy, safety, expense, and utility needed for acceptance. This is fertile ground for creative research.

Pellet Quality Issues

Since its introduction in the 1930s, pelleting has become an important process to the feed industry. Estimates vary on the percentage of annual feed production that is pelleted but it is likely in the 60% range.

In recent years there has been a dramatic increase in pelleted feed tonnage because of the rapid growth in hog integration. This industry, like the broiler industry, has concluded that the cost of pelleting is more than offset by improved animal performance.

Pelleted diets can affect animal performance in a variety of ways. The following is a partial list of pelleting attributes that might contribute to improved performance (Behnke, 1994):

1. Decreased feed wastage
2. Reduced selective feeding
3. Decreased ingredient segregation
4. Less time and energy expended for prehension
5. Destruction of pathogenic organisms
6. Thermal modification of starch and protein
7. Improved palatability

The above factors are critical for feeding food producing animals. In the case of pelleted feed for horses, the criteria to be applied are somewhat different. Perhaps most important, however, is the ability to prevent selective feeding. Nearly as important, however, is the value of clean, bright feed to the horse owner. These owners typically place a high value on packaging and "presentation," and pellets do have a role to play in this regard.

In addition, pelleting allows the use of a wider variety of ingredients without obvious changes in the physical properties of the diet. This often will allow diet costs to be reduced with little or no affect on performance.

Research conducted in Europe and North America has shown that pelleted pig nursery diets will increase ADG and G/F by 9 to 10%. Pelleted grower-finisher diets result in an increase of 3 to 5% in ADG and 7 to 10% in G/F (Hanke et al., 1972; Tribble et. al., 1979; Harris et al., 1979; Skoch et al., 1983; Walker et al., 1989; Wondra et al., 1994).

It is accepted that pelleting will improve performance; however, the effect of pellet quality and/or diet fines content on animal performance is poorly understood. Stark (1994) conducted two nursery experiments and a finishing experiment to determine the effects of meal vs. pellets and the effects of fines on pelleted diet performance in pigs. In the nursery studies, Phase II diets were fed for 28 days. In the first study, diets were fed as meal, screened pellets, or screened pellets with 25% fines to reflect a low quality pellet. Pelleting improved gain to feed by 12% compared to the meal diet. There was a trend toward reduced G/F ($P < .07$) if fines were included in the pellet diet.

In the second nursery study, similar treatments were used except fines were included at 15 or 30% rather than 25%. Pelleting increased ADG and G/F by 8% and 15%, respectively, compared to the meal diet. The addition of fines did not affect ADG or F/G ($P < .04$).

In the finishing study, 80 gilts were used to evaluate the effect of diet form and pellet fines on growth performance. The treatments were 1) meal; 2) screened pellets; 3) pellets with 20% fines; 4) pellets with 40% fines; or 5) pellets with 60% fines. Animal performance was not affected by diet form (meal vs. pellet). The presence of fines in the pellets tended to decrease feed efficiency ($P < 0.09$) but did not influence ADG.

In another recent finishing pig study (Wondra et al., 1994), pelleting improved ADG by 4% and G/F by 6%. Feed intake was not affected.

Nearly all broiler and turkey feeds are pelleted. It is well established that pelleting improved both ADG and F/G compared to meal diets. However, recent interest in the broiler industry centers on the effect of pellet quality and dietary fines on bird performance. Scheideler (1991) found that broilers fed 75% pellets (25% fines) had substantially better feed conversion than birds fed 25% pellets (75% fines). Selective feeding and nutrient density changes because of selective feeding were noted during the study.

Turkeys appear to be more sensitive to pellet quality and fines. Several studies have indicated that pellet fines decrease turkey performance (Proudfoot and Hulan, 1982; Salmon, 1985; Moran, 1989; Waibel et al., 1992). Moran (1989) showed a decrease in growth and performance when reground pellets were fed, compared to whole pellets. Proudfoot and Hulan (1982) found decreased turkey performance as fines were increased from 0 to 60%.

Current Issues - Pelleting And Pellet Quality

Perhaps the most challenging issue is the development of the high shear conditioning concept (expanders). Many European manufacturers have incorporated expanders in their pelleting systems over the past decade. Over the past two or three years, the U.S. industry has begun to investigate high shear conditioning as a way to improve pellet quality, mill throughput, feed sanitation, and, ultimately, animal performance. Peisker (1993a,b; 1994) has presented data on the applicability of high shear conditioning. In a broiler feeding study (1993b), the author reported that ME was increased by expander conditioning by nearly 5% in a broiler diet. Significant improvements were found in fat and starch digestion. In an earlier report (Peisker, 1993a), the effect of expansion on starch gelatinization was demonstrated. In general, expansion conditioning doubled the level of gelatinization in feed.

The use of high shear conditioning may have significant application in some animal applications; however, because of capital and operating and maintenance costs, the industry must use judgement in identifying those applications. At present, there are as many as one hundred of these systems on order, under installation, or installed in the U.S. Most are in the poultry industry. There is concern that many of the decisions being made are coming from a “crowd mentality” rather than being justified by factual information under domestic conditions. This is certainly an area that needs further unbiased research.

Another contemporary research topic is the elucidation and control of factors that dictate pellet quality. Formulation has a tremendous impact on pellet quality; however, it is not yet possible to include “pelletability” factors in least cost formulation programs.

Pellet quality issues can be partitioned into several individual components and their contribution of each component. These are: formulation (40%); grind (20%); conditioning (20%); die selection (15%); and cooling/drying (5%). It should be noted that 60% of pellet quality is determined before the feed reaches the pellet mill.

There is significant ongoing disagreement within both swine and poultry integrator companies concerning the affect of pellet fines on animal performance. Traditionally, most broiler integrators have held that there is no advantage of having more than 60% pellets (40% fines) in the feeder pans. Recent privately funded studies, however, have shown that contemporary broilers need at least 80% pellets for optimum performance. In general, swine integrators are finding similar results.

There are actually two issues that must be addressed if a high percentage of pellets is to be presented to the animal. First of all is pellet quality. If a high quality, durable pellet is not produced, no amount of gentle handling will assure a high percentage of pellets at the feeder. If the earlier quality allocation is accurate, we must begin to formulate diets with pellet quality in mind. To date, reliable attributes are not available to use least cost formulation to predict pellet quality. However, there are several charts available that address the relative "pelletability" of most common ingredients.

The second issue is screening operations after cooling. The trend in the U.S. for the last 10 to 15 years has been to build feed mills with no pellet screening equipment. Even in older feed mills, the screens are often by-passed or blanked with sheet metal. The net result is that all fines generated within the feed mill are not re-pelleted but are sent to loadout or bagging and carried to the farm.

Given the size and capacity of today's feed mills, fines generation is unavoidable. Fines contribute to pellet cooling problems, fat or molasses coating problems, segregation, and selective feeding.

One of the easiest and most effective ways to reduce fines delivered to the feeder is to prevent them from leaving the feed mill by screening. Screening operations are not very expensive in terms of capital equipment or operating cost, but if recycle is significant, a reduction in plant throughput equal to the recycle tonnage can be expected. This brings the discussion back to initial pellet quality. If high quality pellets are produced, recycle will be minimized.

Beyond the expander, there have been several recent innovations in pelleting. The first is known as the compactor. This device replaces the standard conditioner and serves a purpose similar to the expander. The compactor will not result in the high levels of gelatinization found with extrusion or expansion but does result in substantial improvements in pellet quality and feed hygiene.

Another novel approach is the Universal Pellet Cooker (UPC) introduced by the Wenger Corporation (Sabetha, KS). This device incorporates long-term conditioning with short-term/high temperature extrusion. The product from the machine is similar to standard pellets in appearance but of higher typical durability. This device may find wide application in specialty feed production such as horse feeds.

Future Trends

Odor Control

Given current trends in dust emission control, the next step may be odor control for feed mills. This is a huge issue with swine production units and is becoming so with many other types of production units. Technology is presently available to reduce odor emission to near zero. However, it is costly and adds no value to the product. If adopted, it will be done only under regulatory enforcement.

Hygienic Treatment of Finished Feeds

Feed manufacturers are under pressure to provide clean, pathogen-free feeds that do not contribute to the health problems of the target animal. Many manufacturers are investigating or initiating Hazard Analysis and Critical Control Point programs to accomplish that goal. Present technology in the form of hydrothermal treatment (i.e., expanders, compactors, UPCs, etc.) can do a great deal; however, it will take a great deal in the form of facility design and management skill to be successful.

In-Line Pellet Moisture and Quality Control

Several prototype and production models of in-line pellet moisture monitors are available. For successful adoption, these monitors must be given feedback control capabilities to be able to control residence time and air flow in coolers. Both temperatures and moisture content are important to shelf-life and must be controlled.

In addition to controlling coolers and dryers, in-line moisture monitoring and control is being adopted in the pre-pellet area. The concept is to refine management of feed moisture to improve pellet quality and production rate while controlling moisture shrink in the final product. At least two suppliers are actively promoting this technology in the feed industry.

Liquid Ingredients

Several major vitamin and animal drug manufacturers are pursuing developments of liquid forms of their products. In addition, several enzyme preparations, designed to improve nutrient availability, are entering the market (e.g., phytase). Often these have a use level of a few ounces per ton. There are several reasons for this development, not the least of which is a reduced cost of manufacturing and improved nutrition that may be shared with the final user.

With the development of mass flow meters and other highly reliable liquid proportioning systems, accurate application rates are feasible down to less than one-half kilogram per ton. When this is coupled with the fact that liquids, when applied properly, do not segregate, it is easy to understand the interest.

Summary

Feed cost represents the major item in the cost of animal production. Without doubt, efforts will continue to refine feed manufacturing techniques to reduce the cost of feed and to increase its value to the target animal. The possibilities for improvements in feed manufacturing are endless; however, the cost of each innovation must be carefully weighed against demonstrated improvements in animal performance.

In some cases, changes in feed manufacturing technology will be dictated, not by animal response, but by other motivations such as regulatory guidelines or health concerns. A case in point is the use of hydrothermal processes, such as pelleting, extrusion, or roasting, to reduce the microbiological load in the feed. The concern has little to do with animal health but will add significantly to the cost of feed.

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