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Binding and other functional characteristics of ingredients

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Formulation and ingredient selection are thought to control about 40% of pellet quality (Behnke, 1996). Oftentimes, ingredients are dictated by economics or nutrient requirements, and the options for change are limited. However, changes in ingredients that make up less than 1% of the formulation can make significant differences. Selection of phosphate source, addition point of fat or the use of binders will all have a strong influence on both the pelleting process and subsequent pellet durability.

This chapter will use corn/soy-based formulations to examine the effect of both macro- and micro-ingredients. The results that will be reported in this chapter are primarily based on personal investigations by the author.

Wheat and cereal grains

Shifting from corn to wheat has a large impact on pellet quality. When wheat is replaced by corn, binders are sometimes added to maintain a consistent product. Two examples are provided that illustrate the influence that changes in these ingredients can have.

A laboratory trial was run using a CPM CL Type 2 pellet mill. The basal ration was a straight 3:1 corn/soy blend. Wheat or lignosulfonate (LS) replaced corn in this mix with no attempt to balance nutrients. Meal was conditioned to 85°C with 2 bar steam. The pellet durability index (PDI) was determined by ASAE Standard 269.1 (the KSU Tumbling Can Method) modified to include two 20 mm hex nuts per chamber (**Table 15-1**). Percent reduction of fines (%ROF) was calculated by comparing the fines from the basal corn/soy ration to those in the test formulations. This number gives the relative "binding" strength associated with each change.

Table 15-1. Effect of Displacing Corn with Wheat or Binder[1].

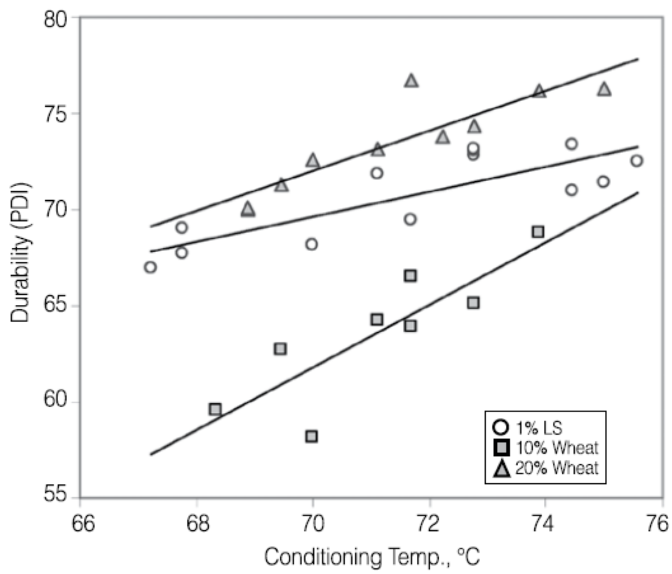
Formulation	PDI[2]	ROF[3], %
0 % Wheat	83.7	0.0
10% Wheat	86.4	16.5
20% Wheat	88.2	28.2
30% Wheat	89.9	38.0
40% Wheat	89.7	36.8
50% Wheat	91.4	47.2
1% lignosulfonate	88.8	31.3

[1]Diet was corn- and soybean meal-based (3:1).
[2]PDI = Pellet Durability Index
[3]ROF = Reduction in fines

A second trial was conducted in a commercial feed mill. A corn/soy turkey ration was formulated to include 10% or 20% wheat or 1.25% lignosulfonate. Pellets were made on a CPM 7800 at a production rate of 35 metric tonnes per hour. Conditioning temperature varied, but was recorded at the time of sampling. Pellet durability was measured using the KSU method with two 20 mm hex nuts in each chamber. Results were plotted as a function of conditioning temperature (**Figure 15-1**). The slope of the trend lines is different for wheat and lignosulfonate, suggesting that wheat is more strongly affected by the addition of conditioning steam. Increasing the level of wheat from 10% to

20% clearly increased pellet durability. Adding 1.25% LS was nearly as effective as 20% wheat, similar to the results achieved in the laboratory trial.

Figure 15-1. Effect of wheat, binder and conditioning temperature on durability of turkey pellets.



A third test was conducted in the laboratory to compare the effect of replacing 12.5% and 25% of the corn with wheat, triticale or barley (**Table 15-2**). Triticale is a hybrid of wheat and rye and its binding characteristics were similar to those of wheat. Replacing corn with barley improved pellet durability, but not to the same degree as was observed with wheat.

Table 15-2. Durability of pellets made with various grains replacing corn[1].

Percent Replaced	Wheat	Triticale	Barley
12.5	84.5	83.4	80.9
25.0	86.9	86.2	84.2

[1]Durability with corn was 79.2

Brewers and distillers grains

Distillers dried grains with solubles (DDGS) were collected from five commercial sources, analyzed and tested for their effect on pellet durability (**Table 15-3**). The formulation for this trial was 70% ground corn, 15% soybean meal and 15% DDGS. Six batches were mixed for each DDGS sample—three were pelleted without binder, and three had an additional 1.25% lignosulfonate added on top of the formulation. Each batch was conditioned to 82°C with 2 bar steam. Durability was measured by the KSU Tumbling method with two 20 mm nuts in each chamber.

Table 15-3. Analyses of DDGS sample source and their effect on pellet quality.

Sample	A	B	C	D	E
Nutrient, %					
Moisture	7.3	10.4	13.6	14.5	22.3
Protein	27.1	25.2	24.5	29.7	23.1
Fat	8.3	9.3	7.4	10.3	7.7
Fiber	13.2	8.3	8.6	9.3	8.4
Ash	2.5	4.5	5.9	4.0	5.3
Particle Size					
US Sieve 12	2.6	11.5	17.6	2.1	3.2
US Sieve 30	40.5	56.8	58.5	56.6	33.8
US Sieve 50	34.6	25.1	16.5	35.3	31.8
US Sieve 100	16.4	5.5	4.7	4.3	19.9
Pan	5.9	1.1	2.7	1.7	11.3
Pellet Durability					
No Binder	75.2	81.2	84.7	83.1	88.7
Binder	83.9	87.3	89.2	89.9	91.7

This test was conducted at the request of a commercial feed producer who had noticed a variation in pellet quality and suspected it was caused by the DDGS. Results confirmed that this was in fact the case. The lesson here is that it may not be appropriate to make a broad statement that an ingredient is good or bad for pelleting. An ingredient's effect on performance may vary depending on its particular attributes. In this case, pellet durability increased with increasing moisture content. Either the drying process deactivated some of the natural binders or the high moisture content was the result of a high level of solubles added to the dried grains.

Brewers grains were also received from five different suppliers and tested. Durabilities once again varied, ranging from 62.9 to 70.7. Although the brewers grains were analyzed in the same manner as the distillers grains, it was not possible to identify a particular factor that could be associated with the different pellet durabilities. In general though, it appeared that brewers grains were a negative factor for pellet quality.

The pelleting performances of brewers grains and distillers grains were compared by preparing composites from the five samples of each of these ingredients. The composited ingredients replaced 15% soybean meal (SBM) in a basal ration that consisted of 70% ground corn and 30% SBM. In preparing these rations it was noted that the SBM was fairly coarse. As a further treatment, a portion of this SBM was milled through a 3 mm screen, and this finer SBM was used in place of the entire portion of the unmilled, coarse SBM. All treatments were prepared with and without 1.25% lignosulfonate binder and tested in triplicate. Pelleting conditions and durability tests were as previously described. Displacing 15% SBM with distillers grains had no effect on pellet durability, while replacement by brewers grains caused a significant drop in durability (**Table 15-4**).

Table 15-4. Comparison of brewers, distillers, and two grind sizes of soybean meal.

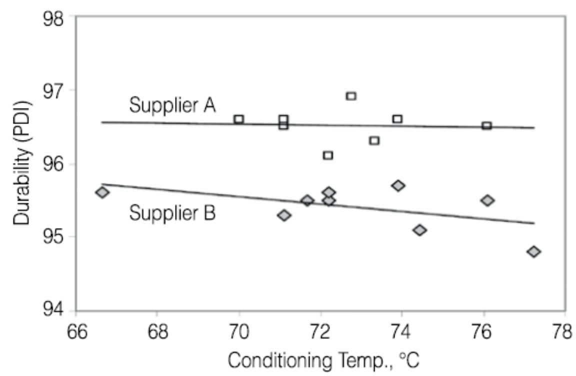
	Coarse SBM	Fine SBM	Brewers	Distillers
Particle Size				
US # 12	12.2	8.6	11.4	10.9
US # 30	41.9	34.8	44.0	43.0
US # 50	18.4	20.0	17.6	18.8
US # 100	11.2	15.0	10.5	11.4
Pan	16.3	21.6	16.5	15.9
Pellet Durability				
No binder	83.9	81.8	70.4	85.6
Binder	90.3	88.4	79.3	90.1

Soybean meal

The previous experiment suggested that particle size of SBM had little effect on pellet durability (**Table 15-4**). Another trial was conducted in a commercial feed mill to compare SBM from two suppliers that were thought to provide different grinds. The trial was run on a 37% all-vegetable protein concentrate that contained 70% SBM. There was a clear difference in pellet durability between the two sources of meal (**Figure 15-2**). However, particle size analyses failed to show a significant difference in grind. Proximate analyses revealed that meal from Supplier B contained 1.0% fat, versus 0.6% from Supplier A. This trial was run on a computerized mill with set points of 150 amps and 72°C. The computer adjusted production rate to achieve the desired amperage. Average production rate with meal containing 1.0% fat was 12.3 metric tonnes per hour, versus 11.2 metric tonnes per hour with 0.6% fat.

It is significant to note that pellet quality did not increase with higher conditioning temperatures. This is a typical response in rations that have a high SBM content, and is much different than is seen with rations high in starch (**Figure 15-1**). The slight negative trend in pellet durability with increasing temperature in this trial was probably related to production rate. The ration based on Supplier B's SBM increased from 10.9 to 13.2 metric tonnes per hour as temperature increased.

Figure 15-2. The effect of conditioning temperature of pellet durability of a 37% all-vegetable protein concentrate.



Fat

Adding fat before pelleting is simply the worst thing that can happen to pellet quality. It might be useful to compare binding a pellet with gluing a chair. It is not enough to simply pour the glue on the wood; the surface must be free of oil and pressure must be applied. Adding fat hurts pellet durability by lubricating the extrusion process, and thereby reducing the pressure that is applied. Furthermore, it creates a hydrophobic film over the feed particles that prevents them from binding together.

A trial was run in a commercial turkey feed operation to determine if conditioning temperature could be increased by the addition of fat—and thereby improve pellet durability. At this particular mill it was impossible to raise the temperature above 77°C without choking. Addition of 1% fat provided lubrication, which allowed pelleting temperature to increase to 82°C, but the negative effect fat had on binding erased any benefit of improved temperature.

Fat should be applied post-pelleting whenever possible. When sprayed onto the hot pellet as it comes off the die, the effect on pellet quality is generally neutral. However, if the pellets are screened and fines returned for re-pelleting, the fat that is returned with the fines will have a strong negative effect. Even when pellets are not screened, fines are sometimes transferred in the air stream to the cyclones and returned to the pellet mill. Application of fat to the pellets after cooling results in the best possible pellet durability. When applied in this manner, the fat tends to stay on the surface of the pellet, reducing dust and lubricating the pellet to reduce abrasion.

Wheat middlings

Midds generally make a good-quality pellet and do not seem to respond strongly to temperature. Dairy feeds that contain 40% midds can be run at 50°C or 70°C with almost no difference in pellet durability.

Clays

Clays are sometimes used as binders for pelleted feeds. They are often inexpensive and may be cost-effective fillers in rations that are not nutritionally dense—e.g., range cubes. Research at Kansas State University (Pfost and Young, 1973) showed that addition of 2% bentonite to a medium-grind corn/soy pellet could reduce fines from 11.7% to 7.8% when conditioning temperature rise was 32°C. However, not all clays are effective binders for pelleting. Five clay binders were evaluated on a pilot plant pellet mill. The basal ration contained 70% ground corn, 30% SBM and vegetable oil on top. A positive control was mixed without oil. Each of five clays was added on top of the ration at a level of 2%. Rations were prepared in triplicate and conditioned to 80°C with 2 bar steam prior to pelleting. Durability with no added fat or binder was 58.9 (**Table 15-5**). This is somewhat low, but not unheard of for swine and poultry pellets. Addition of 2% fat reduced durability to 38.8. Addition of 2% of clay #1, clay #2 and clay #3 showed little or no improvement in durability. Clay #4, a sodium bentonite, brought durability back up to 56.7. Clay #5 had the strongest binder response, in part due to its ability to increase compression by resisting extrusion.

Table 15-5. Effect of clays on pellet durability index (PDI).

Treatment	PDI
No Fat – Control	58.9
2% Fat – Control	38.8
2% Fat – 2% Clay #1	37.2
2% Fat – 2% Clay #2	41.3
2% Fat – 2% Clay #3	45.3
2% Fat – 2% Clay #4	56.7
2% Fat – 2% Clay #5	68.0
2% Fat – 0.5% Lignosulfonate	57.7
2% Fat – 1% Lignosulfonate	67.4

Lignosulfonates

Lignosulfonates are the most widely-used binders in the feed industry (Castaldo, 1998). Early research at Kansas State University (Pfost, 1964) showed that addition of 1% lignosulfonate to a corn/soy turkey finisher pellet could reduce fines from 8.2% to 4.9% when conditioning temperature rise was 28°C and die dimensions were 50 mm by 4.7 mm. Pfost also documented lubrication properties of lignosulfonates and demonstrated that they were effective across a wide range of conditioning temperatures. Lignosulfonates are generally twice as effective as clays (Pfost, 1976; **Table 15-5**) and approximately 15-20 times more effective than wheat (**Table 15-1** and **Figure 15-1**).

Phosphates

Defluorinated (tricalcium) phosphate is known to allow pellet mills to produce at a faster rate (Behnke, 1981). When defluorinated phosphate is replaced by dicalcium phosphate there is increased resistance to extrusion, production rate declines and pellet durability improves. A typical response is seen when dicalcium phosphate in a grower feed is replaced by defluorinated phosphate in a finisher diet (**Table 15-6a**).

Table 15-6a. Effect of P source on pelleted turkey diets.

	Grower Ration	Finisher Ration
Ingredient, %		
Corn	54.0	64.0
SBM, 48.0%	40.0	25.0
Deflour. P	0.0	2.0
Dical P	1.2	0.0
Bakery	0.0	5.5
Pellet Response		
Energy, kWh/tonne	6.5	5.4
Durability, %	87.4	80.9

These rations were run on the same pellet mill, both at 36.4 metric tonnes per hour and 84°C. Dicalcium phosphate in the grower ration increased resistance to extrusion, effectively increasing the amount of energy the pellet mill used to push the pellets through the die (6.5 versus 5.4 kWh/tonne). This extra work increased compaction and made a more durable pellet (87.4 versus 80.9). It is possible that some of the response was caused by the addition of bakery byproduct or a shift in the corn:soy ratio, but the observed result is believed to be typical of the response to phosphate alone. A second example with no bakery byproduct shows similar results (**Table 15-6b**).

Table 15-6b. Effect of P source on pelleted turkey diets.

	Grower Ration	Finisher Ration
Ingredient, %		
Corn	55.0	60.0
SBM, 48.0%	37.0	31.0
Deflour. P	1.1	2.8
Dical P	1.5	0.0
Pellet Response		
Cond. T, °C	77	79
Rate, tonne/hr	22.7	25.0
Energy, kWh/tonne	6.6	4.8
Durability, %	77.8	64.1

Urea

Urea is a very special ingredient. It dissolves in water and its solubility increases with heat. It is also extremely hygroscopic; it will liquefy by pulling moisture from the air. Urea does not give up water easily in the dryer/cooler of the typical pelleting system.

When steam condenses on the feed mix, urea dissolves and increases the percentage of liquid in the mix. When the mixture extrudes through the die it is further heated by friction and more urea dissolves. As soon as the pellet exits the die, moisture begins to be lost by evaporative cooling. As the pellet cools, the dissolved urea solidifies, forms salt bridges between feed particles and acts as a binder. However, as moisture migrates toward the surface of the pellet, it carries dissolved urea with it and leaves it deposited on the surface. Eventually this surface concentration of urea makes further drying difficult, and therefore reduces the rate of heat flow from the pellet (heat is lost most efficiently by evaporation of water).

If the pellets are not cooled through when they are sent to storage, they will eventually release moisture that will migrate to the coolest area of the bin or bag, where it will be absorbed by urea on the surface of pellets. This moisture migration releases bonds and causes the pellets to swell and lose durability. The problems associated with urea pellets are generally not improved by use of commercial pellet binders.

Urea pellets are typically run with very little steam or moisture addition. This limits the amount of urea that will dissolve and also increases die friction. The increased die friction adds “dry” heat to the pellet, which encourages moisture loss when the pellet is in the cooler.

Summary

A list has been compiled that compares many feed ingredients on the basis of their pelleting characteristics (**Table 15-7**). These values were actually selected from a much larger list containing ingredients commonly used in Europe (Payne, 2001). The numbers represent a consensus opinion based on personal pelleting experience. In theory, a system like this might make it possible to formulate a ration to achieve a particular durability level. In practice, interactions between ingredients and variations in pelleting conditions make this difficult. However, the numbers can be useful as general guidelines.

Ingredients clearly impact pellet durability and pelleting efficiency. It is impossible to report on each ingredient in this chapter. Furthermore, these examples have shown that substantial variation can exist within the same ingredient coming from different suppliers. Information that has been provided in this chapter is believed to be generally true and hoped to be helpful. However, the effect of any ingredient must be determined in the pellet in which it will be used.

Table 15-7. Factors affecting pellet durability and die lubrication. (0 = poor, 10 = good)

Ingredient	Durability	Lubrication
Barley meal	5	6
Wheat meal	8	6
Soybean meal	4	5
Brewers grains	3	4
Distillers grains	3	4
Distillers grains with solubles	5	6
Corn gluten meal	5	8
Molasses	7	6
Skim milk powder	9	2
Fat or oil	-40	50
Lignosulfonate	50	30

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