

Reducing the risk of toxic substances in feeds

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The Food Safety Modernization Act (FSMA), which was signed into law Jan. 4, 2011, dictates that animal feeds be considered foods by defining food as “a product intended to be used for food or drink for a human or an animal” and changes the role of the Food & Drug Administration from “correcting food safety problems after they occur” to “working with the food industry to systematically prevent problems.” FSMA requires that feed manufacturers “have a written food safety plan that describes the likely hazards and preventive controls implemented to address those hazards.” In addition, FSMA requires that feed manufacturers be capable of retrieving “the history, use and location of an article of food through all stages of its production, processing, and distribution.”

A close relationship exists between the quality of livestock feed and the quality of animal products offered for human consumption. However, feeds can also be contaminated with a wide variety of compounds via a wide variety of sources. Indeed, the detection of bovine spongiform encephalopathy (BSE) prions, dioxins, mycotoxins, agricultural chemicals, industrial chemicals, microbial pathogens, veterinary drug residues and heavy metals in feeds has focused attention on the role of feeds in contamination.

People and risk management

In view of the complexity of the issues involved with the contaminants listed and the brevity of this article, it is impossible to deal comprehensively with each contaminant. Instead, this article will focus on practical methods to reduce the risk of contamination at the mill level as well as control of strategies for mycotoxins, pathogenic microorganisms and chemical residues.

Risk perspective

Some perspective is in order before beginning our discussion of risk reduction. First, we all realize, I am sure, that zero risk is an impossibility. Like the truck driver who won a safe driving award and was killed in a crash the next week, risk does not end when we do a good job. Risk must be addressed continuously.

Second, there is no such thing as a foolproof system of risk reduction. Someone once said, “Foolproof systems underestimate the ingenuity of the average fool.” Risk reduction programs either continue to improve or they become increasingly ineffective.

Third, and last, in our present agriculturally ignorant, media-driven, litigation-happy culture, feed manufacturers would be well served to employ valid laboratory testing procedures, use on-site testing methods where possible, ask questions, communicate with suppliers regularly and document, document, document.

Risk management tools

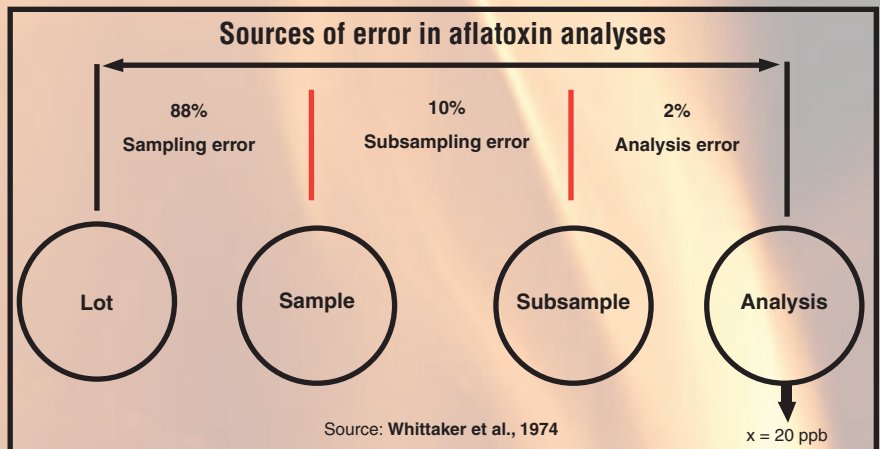
Risk management tools available to feed manufacturers are the same tools to accomplish other missions:

- People,
- Procedures,
- Materials (feed ingredients, fuels, power, etc.) and
- Machinery (formulation equipment, feed delivery systems, feed storage equipment, feed milling equipment, etc.).

A good risk reduction program must blend these “tools” on a consistent basis. However, for brevity and practicality, this article will not address issues involving procedures or machinery. We will, instead focus on the basic concepts involving people and materials in the hope that the discussion will stimulate thinking and innovation.

People are the most important part of the risk reduction process. Clearly, alert, dedicated, team-oriented people are the heart of any risk management program, and employees who do not follow the company policy will undermine the program. Yet, without adequate training, employees cannot effectively support the program. Once hired, employees should be quickly and efficiently trained to do their jobs. This training should include not only what job to do but why their job is important. Employees should be informed initially and periodically reminded of the vital nature of their job.

Yet, what employees are told during training and actual company practices do not always match. For example, an ingredient receiving person is instructed to examine each load and reject loads that do not meet company specifications. If this employee discovers what he/she believes is an unusual load, what happens? Is the employee commended



1. Aflatoxin in multiple samples of corn*

Mill number	Sample numbers										AV
	1	2	3	4	5	6	7	8	9	10	
1	80	269	120	237	150	201	196	178	130	114	167.5
2	160	21	136	16	67	80	90	118	30	52	77.0
3	13	119	31	77	41	49	70	32	77	28	53.7
4	2	90	70	37	22	32	9	54	4	3	32.5
5	41	0	1	27	1	13	10	6	1	0	10.0

*Adapted from Velasco et al., 1975

for her/his efforts (even though they may be wrong) or is he/she chastised for “making a mountain out of a molehill” or “wasting time?” If this person is chastised, what does this say to him/her about the company commitment to risk management?

Employee motivation is a reality faced by virtually every feed mill manager. Employee motivation is a complex affair that is beyond the scope of this article and the expertise of the author. However, Glasser (1990) indicated that employee motivation involves addressing the employee's basic needs for survival, belonging (love), power, fun and freedom. He further stated that since belonging and power are the needs most difficult to satisfy, managers that find ways to empower their employees are “by far the most successful.” Finally, Glasser (1990) stated:

“We cannot consistently control other people; we can control only ourselves. Therefore, the basis of effective lead-managing is to deal with others knowing that you cannot control them, that all you can do is to give them the kind of information that has a good chance of persuading them that the work you ask them to do will feel good as they do it. In practice, workers do not work to satisfy their needs; most do not even know what their needs are. What they want is what we all want — to feel good. If we can help them feel good, they will listen very carefully to what we ask them to do and most of the time, will do it.”

However, it is important to remember that a person's example speaks louder than words. Albert Einstein is reported to have said, “Setting an example is not the main means of influencing others; it is the only means.” Company commitment to risk reduction must be supported by everyone from top management down. Without such a solid commitment, the risk reduction program will not be as effective as it could have been.

Control of molds and mycotoxins

Sampling for mycotoxins in ingredients. In the average feed manufacturing situation (if such a situation exists), feed ingredients represent the largest source of mycotoxins. While sampling for mycotoxins may seem to be a simple matter for most feed manufacturers, the situation is more complex. Perhaps an example will provide some help. The example involves aflatoxin, but similar principles apply to nearly every mycotoxin.

Farmer Brown has been raising corn for years and harvests his crop on schedule. He later dries the corn and stores it for the price to get right. Finally, the price is right and Farmer Brown pulls his corn out of the bin and takes it to the mill. The first mill he visits samples his corn and rejects his corn saying it has more than 100 parts per billion of aflatoxin. The next three mills he visits find more than 20 ppb but less than 100 and reject it. The last mill he visits samples and finds fewer than 20 ppb and unloads his corn. Which mill was right? If we retested the samples collected at each mill, we might say they were all right!

Let's look a bit closer and see why this might be true. Let say each of the five mills that Farmer Brown visited collected a 10 lb. sample. If we took each of these five samples and divided them into 10 one-pound samples and ran those sam-

ples, the results might look like those in Table 1.

You will notice that the results obtained from 1-lb. samples varied from 0 to 269 ppb aflatoxin, while the 10-lb. sample results varied from 10 ppb to 167 ppb. Why is that? Part of the variation is probably due to sheer chance, but let's look even closer. If we could randomly selected kernels of corn so that they represented Farmer Brown's load of corn, and then we ran each kernel for aflatoxin, the results might look like those in Table 2.

The aflatoxin in 200 kernels was concentrated in only seven kernels! These highly contaminated kernels (some of which may have contained 3,500 ppb aflatoxin) are the primary reason we have so much trouble with aflatoxin (and other mycotoxin) assays. If we miss these “hot” kernels, we miss the mycotoxin (in this case, aflatoxin). If we get too many of these kernels, we reject corn that might be good.

The Figure shows that 88% of the error in aflatoxin testing is associated with how the sample was collected from the load. This is why sampling is CRITICAL in mycotoxin testing.

The following suggestions should assist mills in obtaining a representative sample:

1. Probe as many areas of the load as possible.
2. Push the probe to the bottom of the truck.
3. Be alert to signs of hot spots.
4. Collect at least a 10 lb. sample and grind the entire sample. This will blend the “hot” kernels with other kernels, providing a more representative sample.

Managing molds and mycotoxins in feed manufacturing. Mycotoxins are poisonous chemical substances produced by molds as they grow on feed or feed ingredients. Mycotoxins are generally very durable chemically and will not be destroyed during the feed manufacturing process. While molds are generally reduced in numbers as a result of the feed manufacturing process, molds can grow whenever conditions are favorable. Controlling mold growth and mycotoxin production can generally be accomplished by keeping moisture low, keeping feed fresh, keeping equipment clean and using mold inhibitors.

Moisture is the single most important factor in determining if and how rapidly molds will grow in feeds. Moisture in feeds comes from three sources: feed ingredients, feed milling processes and the environment in which the feed is held or stored. To control the moisture content of feeds successfully, moisture from all three sources must be managed.

Since corn and other grains are a primary source of the moisture and molds found in feed, the first important step in managing moisture in feed is to control it in the grains from which the feed is prepared. Since all feed ingredients contain moisture, they should be monitored and their moisture content recorded.

It is commonly believed that the amount of moisture in grain is too small to permit mold growth except in rare and unusual circumstances. However, moisture is not evenly distributed in grain kernels. A batch of grain containing an average of 15.5% moisture may, for example, contain some kernels with 10% moisture and others with 20% moisture. The moisture content of individual grain kernels is directly related to the amount of mold growth that occurs; that is, kernels with higher moisture contents are more susceptible to mold growth. In addition to moisture, the amount of mold growth is about five times greater for broken kernels than for

2. Aflatoxin in 200 corn kernels*

Number of kernels tested	Aflatoxin (ppb)
7	12, 14, 1, 155, 408, 125, 294, 3500
193	All zero

*Adapted from Shotwell et al., 1974

3. Sampling for salmonella in feed mill facilities

Sample type	---Mill personnel collected---			---Researcher collected---		
	No. run	No. pos.	% Pos.	No. run	No. pos.	% Pos.
Feed	42	11	26.19	30	1	3.33
Meat meal	14	12	85.71	2	2	100.00
Fish meal	8	4	50.00	2	0	0.00
Corn	8	1	12.50	1	0	0.00
Liquid fat	8	7	87.50	6	0	0.00
All samples	80	35	43.75	41	3	7.32

Sources of error in aflatoxin analyses*

intact kernels.

The grinding process creates friction, which causes heat to build. If unchecked, temperature increases larger than 10.1°F (5.51°C) will cause significant migration of grain moisture encouraging mold growth. This is particularly true in cold weather when temperature differences can cause moisture to condense on the inside walls of bins. Air-assisted hammermill systems reduce heat buildup in the product and, in turn, reduce moisture problems.

Generally, the pelleting process adds heat and 3-5% moisture to feeds in the form of steam. If the pelleting process is done correctly, this excess moisture is removed from the feed before shipment. However, if this excess moisture is not removed when the pellets are cooled, mold growth will be encouraged. Since feeds containing moisture are warmer than normal, storing hot or warm pellets in a cool bin will cause moisture to condense on the inside of the bin.

Although pelleting of feed has been shown to reduce mold counts by a factor of 100-10,000, many mold spores remain in the feed after it has been pelleted. After pelleting, the remaining spores can grow if conditions are right. Thus, the pelleting process delays, but does not prevent, the onset of mold growth and plays only a minor role in efforts to control molds. In addition, pelleted feeds may be more easily attacked by molds than non-pelleted feeds.

Time is required for both mold growth and mycotoxin production to occur. Therefore, it is important to have feeds delivered often so that they will be fresh when used. Feeds should generally be consumed within 10 days of delivery.

During and after the feed manufacturing process, feeds may come in contact with old feed that has lodged or caked in various locations within the feed manufacturing, storage and delivery systems. This old feed is often very moldy and may "seed" the fresher feed it contacts, increasing the chances of mold growth and mycotoxin formation. To prevent this problem, caked, moldy feed should be removed from all feed manufacturing and handling equipment.

The use of chemical mold inhibitors is only one of several tools useful in the complex process of controlling the growth of molds, and they should not be relied upon exclusively. The main types of mold inhibitors are (1) individual or combinations of organic acids (for example, propionic, sorbic, benzoic and acetic acids), (2) salts of organic acids (for example, calcium propionate and potassium sorbate) and (3) copper sulfate. Solid or liquid forms work equally well if the inhibitor is evenly dispersed through the feed. Generally, the acid form of a mold inhibitor is more active than its corresponding salt.

The particle size of the carriers for mold-inhibiting chemicals should be small so as many particles of feed as possible are contacted. In general, the smaller the inhibitor particles, the greater the effectiveness. Some propionic acid inhibitors rely on the liberation of the chemical in the form of a gas or vapor from fairly large particle carriers. Presumably, the inhibitor then penetrates the air spaces between particles of feed to achieve even dispersion.

Certain feed ingredients may also affect mold inhibitor performance. Protein or mineral supplements (for example, soybean meal, fish meal, poultry byproduct meal and limestone) tend to reduce the effectiveness of propionic acid. These materials can neutralize free acids and convert them to their corresponding salts, which are less active as inhibitors. Dietary fat tends to enhance the activity of organic acids, probably by increasing their penetration into feed particles. Certain unknown factors in corn also alter the effectiveness of organic acid inhibitors.

When mold inhibitors are used at the concentrations typically recommended, they, in essence, produce a period of freedom from mold activity. If a longer mold-free period is desired, a higher concentration of inhibitor should be used. The concentration of the inhibitor begins to decrease almost immediately after it is applied as a result of chemical binding, mold activity or both. When the concentration of the inhibitor is reduced until it is incapable of inhibiting mold growth, the mold begins to use the inhibitor as a food source and grows. In addition, feeds heavily contaminated with molds will require additional amounts of inhibitor to achieve the desired level of protection.

The heat that the feed undergoes during pelleting enhances the effectiveness of organic acids. Generally, the higher the pelleting temperature, the more effective the inhibitor. Once mold activity commences in pellets, however, it proceeds at a faster rate than in non-pelleted feed because the pelleting process that makes feed more readily digestible by animals also makes it more easily digested by molds.

The effectiveness of copper as a mold inhibitor is difficult to document. Although copper sulfate in the diet has been shown to improve bodyweight and feed conversion in broilers, excessive levels of copper may be toxic to young animals and will accumulate in the environment. In addition, recent research has indicated that feeding copper sulfate to poultry causes the formation of mouth lesions similar to those formed by some mycotoxins. Similar mouth lesions might be formed in other animal species as well.

The possible use of inorganic binders (mineral clays) to bind mycotoxins and prevent them from being absorbed by the animal's gut has recently received much research attention. These clay products (including zeolites, bentonite, bleaching clays from refining of canola oil and hydrated sodium calcium aluminosilicates) have been shown to change the response of rats to zearalenone and T-2 toxin. However, it should be clearly understood that the binding of some mycotoxins may be weak or nonexistent and clay products differ in their ability to bind mycotoxins. Nonetheless, many clay products are generally recognized as safe (GRAS) and are used as anti-caking or free-flow additives for feeds.

Since mycotoxins are not evenly distributed in grain or mixed feeds, it is difficult to sample a feed or grain that will give a meaningful result in mycotoxin analyses. Grab samples generally give very low estimates of mycotoxin content. In fact, nearly 90% of the error associated with mycotoxin assays can be attributed to how the original sample was collected. This is because only 1-3% of the kernels in a contaminated lot contain mycotoxin, and these contaminated kernels are usually not evenly distributed within the grain lot.

For whole grains, a properly taken composite sample of at least 10 lb. is required for a reasonably accurate mycotoxin analysis. Trucks can usually be sampled with a grain

probe, but bins must often be sampled as grain is being withdrawn.

Screening of corn for possible aflatoxin contamination using a "black light" was a popular technique 20 years ago. Despite the widespread use of black lighting to screen for aflatoxin and other mycotoxins, research has shown that the technique detects materials that are not mycotoxins and is, therefore, inappropriate. The black light test should never be used for any kind of mycotoxin screening. The minicolumn is a small column that contains silica gel and adsorbents to which sample extracts are applied for detection of aflatoxin. Minicolumns were also very popular for aflatoxin screening until antibody-based test kits became widely available during the last few years. If properly used, the minicolumn test is capable of giving good results for aflatoxin under certain conditions. However, like the black light, it has often been mishandled and misused. The minicolumn is no longer recommended.

Analytical techniques for the detection of mycotoxins continue to improve. Several commercial laboratories now test for a variety of mycotoxins. Although analytical costs can be a constraint, these costs may be insignificant compared to the economic consequences of production and health losses associated with mycotoxin contamination. Commercial antibody test kits for screening or quantification are currently available for aflatoxin, zearalenone, deoxynivalenol, T-2 toxin, ochratoxin A and fumonisins. These antibody methods, while still being improved, are good if properly used.

Control of chemical residues

National surveys have indicated consumers perceive the hazard associated with chemical residues in food to be more serious than that of most other food-related issues. Since chemical residues in foods often occur via feed, it is important to address the issue of chemical residues in feed.

Chemical residues occurring in food are generally of two broad types: antibiotics (or antimicrobials) and other chemicals, which would include pesticides. Since Food & Drug Administration regulations are aimed primarily at the documentation of control of antimicrobials within the feed mill environment, the issue needs no further discussion except to say follow the regulations. In view of the extensive regulations, a similar comment can also be made about BSE prions ... follow the regulations.

FDA routinely tests for 354 pesticides in foods and feeds. Generally few feed or feed-ingredient samples tested by FDA contain illegal chemical residues. Chemical residues were most often found in animal byproducts, grains and plant byproducts. In view of the fact that the finding of a significant chemical residue in food can cause extensive damage to the reputation of a food company as well as a feed company, it is important to address the issue of chemical residues in feeds. Furthermore, experience from previous decades has shown that those who ignore chemical residue issues may be forced to destroy literally millions of pounds of meat, milk or eggs.

As most pesticides in use today have very short half-lives and do not accumulate in animal tissues, it would appear that most of the risk of chemical residues linked to feed would be associated with older chemicals that may still be present within the agricultural environment. Therefore, residue avoidance programs for feed should address the possibility of contamination with older chemicals that have the potential for bioaccumulation within animals consuming those feeds.

Although chlorinated hydrocarbon pesticides, such as DDT, dieldrin and chlordane, were banned from widespread use more than several decades ago, some of these materials apparently still exist and are occasionally used illegally. In addition, industrial chemicals, such as poly-

chlorinated biphenyls (PCBs), are present in antiquated equipment. Thus, chemical residue avoidance testing in feeds should include tests for both chlorinated hydrocarbons and PCBs.

Chemical residue avoidance programs in feed involve two steps: regular testing and sample retention. Regular testing will ensure that chemical residue problems are detected quickly while retention of samples provides companies with a means to track contamination to its source.

Regular testing of feed ingredients for chemical residues should involve testing all major feed ingredients, including liquid fat. Since testing of each individual feed ingredient load for chemical residues can be an expensive proposition, individual ingredient samples may be composited, provided testing procedures are sufficiently sensitive to detect chemical residues.

How long should feed ingredient samples be retained? As a general rule of thumb, it would appear that feed ingredient samples should be retained until products from the animals that consumed the feed have been in consumer channels for two weeks. This procedure will provide feed companies with invaluable information and documentation in the event of a chemical residue incident.

Control of pathogenic microorganisms

Sampling for microorganisms in the feed mill. Sampling is an often over-looked area when gathering information about pathogens in the feed mill environment. Certainly, the collection of adequate samples that represent the batch being sampled is important. However, a more basic question must be addressed. Are we certain that the contamination detected in the feed came from the sample or from the hands of person collecting the sample?

At one feed mill facility, mill personnel were instructed to collect samples while researchers collected samples from many of the same locations. The data from this study are shown in Table 3. A total of 43.75% of the samples collected by the mill personnel were positive for salmonella, while only 7.32% of samples collected by the researchers were positive. These data suggest that proper sample collection is a must if one wants to have a true assessment of contamination.

While a variety of methods exist for dealing with the issue of cross contamination, perhaps one of the simplest is one developed by Jim Andrews of Holly Farms (now Tyson). Paper cups are purchased in a plastic bag. Mill employees are instructed not to touch samples and to keep cups tightly closed within the plastic bag when not in use. Samples are collected only in new paper cups. Cups are used only once and then discarded. Samples are placed in sterile plastic bags following collection for transport to the laboratory. Although simple, this method is quite effective at preventing cross contamination.

Steps toward control of microorganisms in the feed mill. Control of microbial pathogens in feeds and feed mills involves procedures to (1) exclude pathogens from the feed, (2) prevent multiplication of the organism in the feed and (3) kill pathogens within the feed and prevent recontamination.

It should be clearly understood that feed milling processes are incapable of killing certain pathogens (i.e., spore formers). Thus, these pathogens MUST be excluded for control. Furthermore, even when feed mill processes destroy pathogens, higher numbers of these pathogens in feeds require ever-harsher treatments. Harsher treatments cause nutritional damage to the feed as well as costing more. Thus, in reality, each of these control procedures is interdependent and must be pursued simultaneously.

Basic steps in excluding the pathogens from feed. Pathogens may enter feed through any number of routes. However, the primary routes for entry to the feed are through

ingredients, vermin within the mill or cross contamination in the mill. Ingredient quality is important as far as nutritional composition is concerned and is also important in terms of microbiological quality. Ingredients are a major source of pathogen entry into the feed.

1. Obtain clean ingredients. The nutrients that allow animals to grow are also the nutrients that allow pathogens to survive and, in certain situations, to multiply. Animal proteins are often considered high-risk products as far as pathogen incidence is concerned. However, contamination of oilseed meals, such as soybean, cottonseed, rapeseed, palm kernel and canola, has also been observed. In addition, contamination has also been reported in grain and grain byproducts, such as wheat midds. However, any ingredient can be contaminated. Therefore, it is important that all feed ingredients be obtained from reputable suppliers that implement pathogen control measures.

2. Verify ingredient quality. It is important to thoroughly check grains and other ingredients for signs of infestation, such as bird or rat feces, that can carry pathogens, before accepting any ingredient. Bagged and bulk ingredients should be visually inspected on arrival for signs of moisture penetration, insects or rodent attack. Incoming trucks and rail cars should also be checked for cleanliness. Affected bags or bulk ingredients should be refused if standards are not met.

3. Maintain a clean receiving area. Feed spillage around the receiving area should be cleaned up immediately to ensure that there is no feed material to attract birds and rodents. Once ingredients have been accepted, care should be taken to prevent contamination in the receiving area. This area should be free of pests, have a hard-surfaced floor and be well drained and covered. Catwalks in the receiving area collect dust and can be a source of contamination. Air currents and machine vibrations can cause accumulated dust and dirt to drop from the catwalks directly into feed ingredients. Regular cleanups of catwalks, false ceilings, overhead beams and girders will reduce the potential for pathogen contamination from these sources.

4. Control dust. No dust or caked material should be present at any point within the mill, as these materials can provide a media for pathogen survival or growth. A dust collection system is important, as it will keep the amount of dust down. Venting to the outside, separate from intake, will remove potentially contaminated dust. The installation of filters capable of ensuring that dust-laden air is not being drawn in through the ventilation system will minimize recirculation of potentially contaminated dust.

Filters should be installed on intakes through which air is being drawn to cool pellets. These filters will prevent air that is contaminated with pathogens from contaminating pellets. A schedule should be established, according to manufacturer's instructions, to replace filters frequently and routinely. Circulating air from the finished product area to the raw ingredient area will also minimize airborne contamination.

5. Clean up feed spills. Feed spills in the feed mill can provide a medium for pathogen spread and are a source of recontamination, as they can be tracked to other areas. This material should be thrown out or, if clean, quickly recovered. While this material can be reprocessed (pelleted), caution should be used since wet materials can encourage pathogen multiplication. Always discard wet material.

6. Proper feed storage. Separate bulk bin storage should be designated for either mash or pelleted feeds to prevent cross contamination of pellets by residues of feeds that have not been heat-treated. Finished products should always be packaged in new or properly sanitized bags since pathogens can survive for months on bag material.

In addition, it must be recognized that pathogens can survive for long periods in the feed mill environment. Thus, ingredients should be stored in structures, containers or bins that will keep out moisture. Specific bins

should be designated exclusively for storage of high-risk ingredients, such as meat and bone meal. If possible, dedicated delivery lines for these high-risk ingredients are preferable.

Prevent multiplication of pathogens in feed. The lack of moisture is the primary reason pathogens do not rapidly multiply in feeds. Thus, the primary task in preventing pathogen multiplication in feed is moisture control. Obvious sources of moisture, such as roof leaks, uninsulated pipes or areas where wind can blow in rain, must be eliminated. It should also be recognized that water should not be used to clean feed manufacturing facilities, unless there is no other alternative.

Contamination of conveying equipment may be associated with areas of high humidity or moisture. In feed mills utilizing a heat-treatment process (e.g., pelleting or extrusion), the environmental conditions (i.e., temperature and humidity) of the cooler are ideal for the establishment of a microcosm of bacteria and mold. Dust and feed particles adhere to the internal surfaces of the cooler and become media for pathogen growth. As feed passing through the cooler comes into contact with these particles, the feed becomes contaminated, and this contamination spreads throughout the downstream conveying system. This route of contamination of feed/feed ingredients occurs not only in feed mills, but also in rendering plants, vegetable oilseed plants and blending operations. Implementation of a dry-cleaning process or disinfection of equipment often aids in addressing the problem.

Kill pathogens in feed and prevent recontamination. Temperatures of 250°F (122°C) for 15 minutes are required to kill certain spore-forming pathogens. Clearly, it is virtually impossible to meet these time and temperature requirements during the feed manufacturing process. Therefore, spore-forming pathogens such as clostridium and bacillus must be dealt with in some alternative fashion.

There are only two practical methods to reliably kill pathogens in feed: pelleting or extrusion, and chemical treatment of the feed. As previously mentioned, as pathogen numbers increase, longer times, elevated temperatures or higher chemical levels will be required to eliminate the organism from feed.

The pelleting process is effective at reducing the isolation rates of certain pathogens, but pelleting does not eliminate pathogens from feed, and feeds can be recontaminated after the pelleting process. Although pelleting is effective at killing most salmonella in feeds, the pelleting process is highly dependent on the formula.

Certain formulas are capable of receiving tremendous quantities of heat, while others can receive little or none. Extrusion or expansion overcomes some of the difficulties of pelleting and it involves much higher temperatures than pelleting. Thus, extrusion or expansion should be more effective than pelleting at killing pathogens. Nevertheless, regardless of the temperature, feeds exposed to heat treatment (either pelleting or extrusion) must be cooled to remove excess heat and moisture. The cooling process can recontaminate feeds with pathogens, reducing the benefit of the heat-treatment process. The pelleting or extrusion process has no residual activity, so feeds can be easily recontaminated at any time they are exposed to pathogens.

Chemical preservatives have also been utilized to kill pathogens in feed and feed ingredients. Most of these products contain propionic or formic acid or salts of these acids. The propionic acid products were recommended at about 3 kg per ton (6.6 lb. per ton), while the lone formic acid product mentioned was recommended at 6.8 kg per ton (15 lb. per ton). Although researchers often simply catalog manufacturer's recommendations for the products listed and manufacturers can and do test products for efficacy, the method used for evaluating chemical preservatives can greatly influence the outcome of efficacy tests.

In addition, certain products (such as propionic acid) may have no significant inhibitory effect on pathogens in unsterilized poultry feed, but was completely inhibitory when the same feed was sterilized. While no one in the commercial poultry industry uses sterilized feed, interestingly, even when tests are run with sterilized feeds (and unrealistic test conditions), tests show that there are limits to the effectiveness of these products. For instance, one test showed that a level of 5 kg per ton was effective at eliminating pathogen levels of 10^2 , but not levels of 10^6 bacterial cells per gram of dry feed.

A number of fatty acids have been tested for their ability to kill enteric organisms in unsterilized feed. Formic acid has been shown to be more potent than propionic acid in unsterilized feeds with moistures of less than 16%. Indeed, another study demonstrated that when chickens are fed feeds containing pathogens under controlled conditions, a dose-response relationship exists between formic acid

and the incidence of the pathogen isolation in cecal contents.

While encouraging, such data do not account for every eventuality. It is not uncommon for feed moisture to increase following manufacture. This moisture may be from roof or storage tank leaks or may result from condensation. When this occurs, none of the organic acids have been shown to prevent the multiplication of pathogens. Only formaldehyde-0.1% has been shown to prevent the multiplication of pathogens.

In addition, a recent research study has shown that when feeds containing acids were inoculated with salmonella, the organism could still be detected in feeds if detection procedures contained a step that neutralized the acid. Thus, acids may simply interfere with detection procedures, rather than kill the organism. The same study could not detect salmonella in feeds containing formaldehyde even when the compound was neutralized. ■

