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Table of Contents

NIR Prediction For Total And Digestible Amino Acids In Feedstuff: A Rapid Approach Towards Accurate Diet Formulation

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Summary
The recent advancement in Near Infrared Reflectance Spectroscopy (NIR) technology provides a rapid approach for routing quality control in feed industry. Unfortunately, most feed manufacturers only possess NIR calibration for proximate nutrients, such as moisture, protein, fats and ash. These parameters bear limited weight comparing to calibrations for total and digestible amino acids (TAA, DAA) in terms of formulation accuracy and consistency. This paper discusses the accuracy and practical benefits of TAA and DAA calibrations in poultry diet formulation.

Feed Ingredients' Variation
For most feed ingredients, variation in nutritional value widely prevails which represents substantial economics in feed industry. Table 1 shows an example, meat and bone meal, its coefficients of digestible amino acids vary as much as 30%, corn and soybean meal, which are considered less variable, still have a CV of about 10%.

Table 1. Variation of digestible lysine and methionine in three major ingredients*

	Digestible Lys (%)			Digestible Met (%)		
	Mean	Std	CV	Mean	Std	CV
Corn	0.196	0.025	12.76	0.168	0.058	34.52
Soybean meal	2.31	0.37	16.03	0.55	0.05	9.09
M&B meal	2.11	0.58	27.49	0.68	0.19	27.94

The mean, standard deviation (std) and coefficient of variation (CV) of digestible lysine (Lys) and methionine (Met) were calculated based on Samples in Adisseo NIR calibration database.

Generally, feed manufacturers do not analyze the total amino acids (TAA) for each batch of incoming ingredients. Nutritionists draw a large amount of information from the contents of TAA and digestible amino acids (DAA) from several reference databases (NRC, 1998; Parsons, 1990a; Rhone Poulenc Animal Nutrition, 1993) or by using certain coefficients to estimate availability of amino acids. However, table values for most processed feedstuff like animal meal or oilseed by-products, are often inaccurate in DAA contents because high variations among batches are the very nature of these category of ingredients.

In order to counterbalance this variation, nutritionists apply various degrees of safety margins in diet formulation based on book values. The safety margins may vary from 3-10% and represent costs to the feed manufacturers. These costs are hidden and generally regarded as normal formula costs. Their impact is substantial and can affect the economic performance of the manufacturers. Moreover, the actual nutritive values in the finished feeds do not always match with the expected specifications between feed batches because of inconsistency in nutrient values among batches (Ru et al., 2002).

The indirect methods, such as nitrogen technique or protein KOH solubility, none of them actually measures amino acid digestibility per se, and correlation to each digestible amino acid is not always good. In particular, when using nitrogen technique to estimate digestible lysine or digestible sulfur amino acids, the regression is rather poor ($r<0.6$. Kempen et al., 1998). Although the traditional wet chemistry methods are accurate in determining TAA and DAA, feedmills cannot employ these methods for routine quality control of feedstuffs, or precision of diet formulation due to disadvantages such as time constraints, labor intensive and cost considerations.

The recent advancement in Near Infrared Reflectance Spectroscopy (NIR) technology provides a rapid approach for routing quality control in feed industry. Unfortunately, most feed manufacturers only possess calibration to predict proximate nutrients, such as moisture, protein, fat, ash, fiber, etc., in raw ingredients and finished products. These parameters, however, bear limited relevance to the

accuracy of diet formulation and consistency of the finished feeds in comparison with TAA and DAA. It has been well recognized that adding a small amount of synthetic amino acids into broiler diet can yield significant improvements in chicken performance. Therefore, rapid determination or prediction of TAA and DAA in feedstuff will greatly facilitate feed mills to formulate diets thus reduce the magnitude of safety margin.

Several studies have been reported to use NIR to predict amino acids in feed ingredients commonly used for broiler feed industry; while few reported using NIR to predict TAA and DAA for feed ingredients. This paper, taking Adisseo NIR TAA and DAA calibrations as an example, discusses the accuracy and advantages of using NIR in predicting TAA and DAA in commonly used ingredients such as soybean meal, animal meal and cereals.

Development of NIR Calibrations

Adisseo inherited all valuable NIR calibration assets from Rhone Poulenc Animal Nutrition and Aventis. The main components include all reference samples with digestibility data, methodology, core database to develop NIR calibrations etc. The company's development on calibrations has crossed more than two decades and is still growing.

- Animal meal TAA and DAA calibration database. A total of 177 animal meal samples was collected from global wide, mainly consisting of meat and bone meal (MBM), poultry by-product meals (PBM) and fish meal. 108 samples were determined for in vivo digestibility of each amino acid (DAA).
- Soybean meal TAA and DAA calibration database. A total of 74 SBM samples was collected from Europe, U.S., China, Brazil, Russia, Indian, Argentina, etc. of which, 38 samples were determined for in vivo digestibility study on essential amino acids (DAA). These samples contain crude protein from 42 – 50%, lysine from 2.18 to 3.02%.
- Cereal TAA and DAA calibration database. The TAA calibration is composed of 165 cereal samples including corn, wheat, barley and sorghum. DAA database consists of 42 corn, 24 wheat, 10 barley samples.
- Ileal digestibility assay. The true ileal digestibility of each amino acid was determined with caecectomized cockerels using procedures described by Green et al. (1987). Birds were force-fed 50g test diet with 18% CP, excreta were quantitatively collected for a period of 48 h. The excreta and tested samples were analyzed for total amino acids by HPLC, with precision of 3% on pea, 4% on corn and 3% on soybean meal. Through ring-test across European Union laboratories, Adisseo HPLC analytical results on each amino acid bear difference within 2% in comparison with those of European Union standards.
- Calibration development. Calibration was developed by using NIRSystems model 6500, and Winisi II software and partial least squares (PLS) regression with math treatment 2, 5, 5, 1. Soybean meal TAA calibration was later expanded with 27 other oilseed meals, such as canola, groundnut meal, sesame meals for other amino acids, except for total lysine, DAA calibration is expanded with 10 other oilseed meal samples.
- Nitrogen based regression technique. Using the same samples as used for developing NIR DAA calibrations to calculate correlation of nitrogen content with total & digestible Lys, Met, sulfur amino acids and Thr.

Performance of NIR Calibrations

Statistics of NIR TAA and DAA Calibrations

Results in Table 2 show that animal meal NIR calibration has the best regression coefficients for either total or digestible amino acids, its calibration is able to explain 84 – 96% of variation of the four amino acids. For soybean meal, the NIR calibration explains 75 – 91% variation of total or digestible Lys, Met and Thr, but less for total and digestible Met + Cys (SAA). Probably the low R2 value of SAA reflects higher variation of analyzed Cys and a lower accuracy of the analytical method. For cereal ingredients, the NIR calibration covers 79 – 85% variation in the contents of Lys, SAA and Thr. However, it is only able to explain 60 – 65% of variation for digestible Lys and Thr, and 50% of variation

Table 2. Statistics of NIR calibrations for selected important amino acids

CALIBRATIONS	Animal meals				Soybean meals				Cereals			
	N	Mean (%)	R^2	SECV (%)	N	Mean (%)	R^2	SECV (%)	N	Mean (%)	R^2	SECV (%)
Protein	169	57.86	0.92	2.84	101	44.26	0.90	1.13	132	8.86	0.98	0.23
Total Amino Acids												
Lysine	170	3.07	0.96	0.21	74	2.74	0.78	0.09	130	0.26	0.85	0.02
Methionine	168	0.97	0.94	0.09	101	0.62	0.74	0.03	133	0.17	0.65	0.01
SAA	166	1.77	0.94	0.18	94	1.25	0.57	0.09	137	0.35	0.79	0.03
Threonine	170	2.14	0.94	0.14	99	1.7	0.89	0.07	124	0.29	0.84	0.01
Digestible Amino Acids												
Lysine	106	2.52	0.91	0.32	48	1.97	0.91	0.19	67	0.22	0.61	0.03
Methionine	106	0.86	0.93	0.11	49	0.54	0.75	0.03	72	0.16	0.50	0.02
SAA	103	1.34	0.84	0.22	49	1.02	0.57	0.11	69	0.31	0.48	0.04
Threonine	105	1.71	0.86	0.19	49	1.32	0.85	0.1	68	0.26	0.65	0.02

N = the numbers of samples were used to develop each calibration.
R2 = fraction of sample variation explained by the NIR regression equation
SECV = the standard error of cross validation (the average difference between lab values and predicted values of samples when applying the equation in practice to predict unknown samples.

for digestible Met and SAA. The low correlation of NIR data to *in vivo* DAA, particularly for SAA, is probably linked to low levels of these amino acids in cereal samples, and relatively large errors occurring in animal trials and HPLC analyses.

NIR Calibration Superior to N-regression Technique in Predicting Content of TAA and DAA

Results in Table 3 demonstrate that directly using NIR calibration to predict four important amino acids (either total or digestible) is clearly superior to N based technique for animal meals. The NIR is able to explain 20 – 50% more variations than the N-based regression. In reality, if one were to estimate DAA from the N- regression technique, some 50% of batches of produced feeds will be under or over formulated.

Table 3. Comparison of regression coefficients from NIR calibration and N-based regression to estimate total and digestible amino acids in raw materials*

		Lys	Dlys	Met	Dmet	Met + Cys	D M+C	Thr	DThr
Animal meals a	r2 (NIR)	0.97	0.91	0.94	0.93	0.94	0.84	0.94	0.86
	r2 (nitrogen)	0.56	0.46	0.52	0.47	0.44	0.32	0.73	0.67
SBM b	r2 (NIR)	0.92	0.91	0.74	0.75	0.57	0.57	0.89	0.85
	r2 (nitrogen)	0.63	0.46	0.64	0.68	0.52	0.66	0.76	0.19
Cereal c	r2 (NIR)	0.85	0.61	0.65	0.50	0.79	0.48	0.84	0.65
	r2 (nitrogen)	0.73	0.58	0.27	0.17	0.68	0.52	0.69	0.40

**. r^2 (nitrogen) and r^2 (NIR) regressions coefficients were calculated based on data used for developing NIR DAA calibration for each category ingredient.*
a. animal meals were composed of meat & bone meal, fish meal, poultry by-product meal and feather meal.
b. r^2 (NIR) for soybean meal (SBM) anchored with 11 additional oilseed meal samples.
c. Cereal samples were mainly composed of corn, wheat samples.

For SBM samples, using NIR to estimate total and digestible Lys and Thr is particularly superior and robust to N- regression technique, with an increase in accuracy by 30 – 66%. For total and digestible Met, however, the NIR calibration can only improve by 7 –10%. In addition, NIR did not show any advantage in estimating total and digestible SAA in comparison with N-regression technique when Cys was added. This is again likely to be linkeed to the high variation of reference where the Cys data was obtained.

For cereal samples, the NIR calibration is better than N-based regression to estimate the content of total and digestible Met and Thr, with an increase in accuracy by 25 – 38%. For total Lys and Thr, NIR improved 12 – 15% more than the N-based regression. For digestible Lys and Met+Cys, both methods seem to perform equally less accurately.

Table 4. Comparison of contents of digestible amino acids from NIR and *in vivo* for SBM and corn*

	SBM					Corn				
	NIR	in vivo	Abs.diff.	Rela. Diff.	NIR error	NIR	in vivo	Abs.diff.	Rela. Diff.	NIR error
Lys	2.555	2.465	-0.09	101.19	0.19	0.140	0.190	0.050	-73.49	0.03
Met	0.515	0.525	0.010	-97.57	0.03	0.100	0.130	0.030	-76.79	0.02
SAA	1.020	0.980	-0.040	103.10	0.11	0.280	0.245	-0.035	114.04	0.04
Thr	1.485	1.475	-0.010	-99.20	0.09	0.210	0.205	-0.005	102.23	0.02
Trp	0.555	0.570	0.015	-96.80	0.06	0.050	0.050	0.000	-99.95	0.01
Val	1.990	1.995	0.005	-97.75	0.15	0.260	0.340	0.080	-76.13	0.04
Ile	1.860	1.925	0.065	-94.70	0.12	0.230	0.240	0.010	-95.59	0.02
Leu	2.890	3.215	0.325	-86.68	0.14	0.940	0.900	-0.040	103.54	0.07
Phe	2.075	2.145	0.070	-94.59	0.12	0.390	0.340	-0.050	114.37	0.03
His	1.195	1.070	-0.125	110.61	0.10	0.190	0.195	0.005	-97.24	0.02
Arg	3.195	3.145	-0.050	-98.44	0.28	0.260	0.335	0.075	-77.28	0.04

**. All NIR and in vivo data were from Adisseo, France.*

NIR Prediction vs. HPLC and in vivo Results

After the establishment of the TAA calibrations, the first validation test was conducted in the year 1999. Results showed that predictive differences (error) between NIR and wet chemistry were 3.5 and 2.9% for lysine, 3.9 and 7.0% for methionine in SBM, respectively. For corn, the difference was 5.8% for lysine. The cost of in vivo study on the digestibility of each amino acid is prohibitive to test many unknown samples to validate digestible AA calibration. Nevertheless, two SBM and two corn samples were determined to indicate the performance of DAA calibration, with results shown in Table 4. Generally, NIR digestible data were slightly lower than true in vivo values, however, most predicted DAA values only had 1 – 5% difference from in vivo values for SBM samples.

The practical use of NIR SBM calibration has generated results suggesting NIR predictions for Lys, Met and total sulphur amino acids and Try, are even better than HPLC values from a number of feedmill and commercial laboratories in Asia (Table 5). A typical feedback from a customer in Malaysia also indicated that NIR DAA calibration was reliable, predicting DAA profiles that were close to in vivo tested values (Table 6).

Table 5. 1998 ASA ring test summary for US SBM*

	CP	Lys	Met	Cys	Arg	Thr
University	45.7	2.750	0.641	0.716	3.252	1.814
Surveyor	46.5	2.490	0.443	0.749	3.275	1.779
Feedmill	45.9	2.641	0.652	0.844	3.205	1.873
Commercial	45.2	2.646	0.575			
NIR	47.4	2.781	0.607	0.597	3.726	1.666
Government	46.0	2.804	0.581	0.628	3.192	1.766

**. Adapted from Swick, R. A. (1999).*

Table 6. Feedback from customers on reliability of NIR predicted total and digestible amino acids

		Protein (%)		Lys (%)		Met (%)		SAA (%)		Dlys (%)		Dmet (%)		DSAA (%)	
		NIR	Lab*	NIR	Lab*	NIR	Lab*	NIR	Lab*	NIR	Lab*	NIR	Lab*	NIR	Lab*
Avg	N=20	46.98	46.50	2.93	2.90	0.69	0.67	1.33	1.38	2.74	2.70	0.60	0.64	1.12	1.27
Std		0.66		0.05		0.02		0.03		0.03		0.02		0.03	
C.V		1.40		1.71		2.69		2.03		1.13		3.65		2.34	
Min		44.60		2.76		0.62		1.22		2.65		0.53		1.05	
Max		47.58		2.99		0.71		1.36		2.78		0.62		1.16	

** Lab data provided by SBM supplier, Soon Soon manufacture, Malaysia of Lay Hong feed mill; SBM samples scanned by Lay hong's NIR which was standardized with Adisseo and predicted by Adisseo SBM calibration.*

Using TAA & DAA Calibration to Improve Formulation Accuracy and Profitability

A trial was conducted in Colorado Quality Research, France, to verify reliability of the predicted TAA and DAA and practical value in broiler diet formulation. Four treatments of broiler diet formulation containing same levels of energy and amino acids were designed as following:

1. Formulation using table values (Rhone Poulenc Animal Nutrition, 1993) for ingredient nutrient composition (TAA table)
2. Formulation using NIR measured TAA
3. Formulation using DAA table values (Rhone Poulenc Animal Nutrition, 1993)
4. Formulation using NIR DAA values

Performance results in Table 7 showed that although price per ton feed from using NIR values was slightly higher than that from using book values, the net income was increased by $0.038/bird by using NIR TAA values, while using NIR DAA values gained extra $0.036/bird, in comparison with formulations based on book DAA values.

Table 7. Comparing the effect of diet formulation by using TAA and DAA values from NIR and book on chicken performance*

	TAA table	TAA NIR	P value	DAA table	DAA NIR	P value
Average feed price ($/ton)	130.37	132.81		128.78	131.57	
Weight at 49 days (kg)	2.77	2.815	P<0.1	2.73	2.779	P<0.1
Feed consumption (kg/bird)	4.89	4.89	NS	4.85	4.92	P<0.1
Feed cost ($/bird)	0.7	0.72		0.69	0.71	
Feed conversion	1.765	1.737	P<0.0001	1.778	1.769	NS
Processing weight (kg)	2.816	2.859	P<0.01	2.766	2.811	P<0.01
Chill Weight (kg)	2.036	2.077	P<0.01	1.993	2.041	P<0.01
Breast weight (kg)	0.492	0.504	P<0.01	0.476	0.492	P<0.01
Percent breast weight (%)	24.12	24.25	P<0.05	23.87	24.07	P<0.01
Value breast per bird ($ 1.28/lb)	1.388	1.422		1.343	1.388	
Net income per bird breast ($/bird)	0.686	0.706		0.654	0.675	
Difference with NIR ($/breast)		0.021		0.021		
Value whole bird (0.57/lb)	2.558	2.61		2.504	2.565	
Net income ($/bird)	1.856	1.894		1.815	1.852	
Difference with NIR ($/bird)		0.038		0.036		

** Adapted from Thierry Julia, Adisseo (2002).*

Conclusion

NIR TAA & DAA calibrations are able to explain 84 – 96% of variation of the total or digestible Lys, Met, SAA and Thr in animal meals, and 75 – 91% variation of total or digestible Lys, Met and Thr in soybean meal, and 79 – 85% variation in the content of Lys, SAA and Thr, and less explanation for variations in digestible amino acids (50 – 65 %) for cereals. Compared with N-based regression, NIR is more accurate and explains more variations of TAA and DAA values in feedstuffs especially in animal meal and soybean meal, where improvements ranged from 20 – 66%. The real time rapid prediction for TAA and DAA opens more possibility and a valuable approach for feed manufacturers and nutritionists to reduce over-formulation and fine-tune its use of feed raw materials, thus improving their profitability.

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Use Of Tracers For Continuous Quality Assurance Of Formula Feeds

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Today, we work not in an international marketplace but in a global one becoming progressively more prosperous and demanding. Formula feeds are being treated like foods in the European Union as well as in other developed countries with HACCP (Hazard Analysis Critical Control Point) and GMP+ (Good Manufacturing Practices) and complete "traceability" is becoming a basic requirement. Demanding standards being implemented in the European Union are also becoming minimum requirements in developing countries that export to Europe.

One component in "traceability" is being able to know on a "real time" basis that critical microingredients are added to feeds where they are intended and that they are not occurring in feeds where they may be toxic or lead to harmful residues in meat, poultry or fish. The use of tracers to address this issue has been established in the United States, Canada, Western Europe, Australia and other developed markets for many years. Such uses are not widespread yet in Asia but they are likely to come soon.

Historical Uses on Tracers for Continuous Quality Assurance of Feeds

Tracer Use to Control Vitamin D3 Addition to Poultry Feeds

The earliest use of a tracer in formula feeds occurred in the mid-1950s when Agway, a major feed cooperative colored whole kernals of corn and included these in their poultry vitamin premixes so the company could visually confirm vitamins were added to their feeds. Agway's greatest concern was that vitamin D3 be added to every batch of feed. It operated more than 15 feedmills, and it had experienced manufacturing errors that had caused nutritional damage to poultry with sizable economic losses. Vitamin D3 is a critical additive to poultry feeds where the birds are grown indoors with little or no exposure to sunlight, a natural source of the vitamin. While the use of colored corn as a tracer for the vitamin premix worked effectively, it was a cumbersome and expensive approach costing $1/ton of feed or more.

From the early 1960s onwards Nopco Chemical, then Diamond Shamrock, then Alpharma and finally today AgD Nutrition (1) have marketed vitamin D3 colored with blue food dye. Premix manufacturers and feed manufacturers can visually see the blue colored particles in premixes and immediately know the vitamin has been added to the premix. With some effort, the blue colored particles can be observed in mash feeds though the dye may wash out in pelleted feeds and in all cases the "test" is designed to be qualitative only.

As early as the mid-1960s, Agway and then Ralston Purina Company employed first colored graphite particles and later colored iron particles as tracers (2) to code the addition of either the pure vitamin D3 or a vitamin premix containing vitamin D3 to poultry feeds.

The graphite tracers were isolated from feeds via sedimentation in perchlorethylene (dry cleaning solution) with the tracer sedimenting with other mineral matter. The sediment was dried and then sprinkled onto a large filter paper wetted with a 50% ethanol solution. The dye would dissolve in the solution and yield colored spots on the paper. The graphite tracers withstood pelleting with typical "recovery" of the tracer 65% of that added with spots being countable from pelleted feeds. Recovery

Footnotes:

1. *Blue colored vitamin D3 is sold commercially as: Colorguard D (tm) manufactured by AgD Nutrition, Chicago, Illinois USA.*
2. *Colored iron particulates and fine colored iron powder are sold commercially as Microtracers (tm) manufactured by Micro-Tracers,Inc. 1370 Van Dyke Avenue, San Francisco, Ca. 94124 USA.*

from mash feeds was typically 75% or better and from premixes and mash feed samples taken from a mixer, typically 100% of that added.

The iron tracers were isolated from feeds magnetically, sprinkled onto a filter paper with the paper then wetted with 50% ethanol with the dye dissolving in the solution yielding colored spots on the paper. The iron tracers also withstood pelleting with recoveries similar to those found from colored graphite particles.

Feed manufacturers utilizing the colored graphite particles would test hundreds of "retain samples" from truckloads of feed in a central laboratory with test results available within 2 or 3 days of the feed being manufactured. While the results were not "real time" they were quick enough to allow recall of a feed before damage could occur if a manufacturing error was detected. Often, three or more different colored tracers would be used to code different premixes.

Feed manufacturers utilizing the colored iron particles would have their feedmill personnel, sometimes truckdrivers, test large numbers of samples before the feed left the feedmill obtaining "real time" information on manufacturing errors if or when they occurred. Errors could thereby be caught at the feedmill before feed was shipped. Test results were qualitative, though the test could be run quantitatively when necessary.

The philosophy behind this testing was always that the testing would not prevent every manufacturing error but that if it prevented 95% of manufacturing errors and if such errors occurred rarely (i.e. once a year), then the feed manufacturer could tolerate one error every 20 years! Even if the tracer result is run correctly, the sample analyzed may not be representative of the truckload of feed. In any event, the feed manufacturer was utilizing "state of the art" technology to prevent as many errors as it reasonably could.

Tracer Use To Control Therapeutic Drugs, Antibiotics And Coccidiostats Added To Formula Feeds

a. Tracer use to prevent feed manufacturing errors that could lead to toxicity problems
The first use of a tracer for continuous control of a medicated feed occurred in 1986 when a major USA poultry integration manufacturing broiler and turkey feeds at the same feedmill required its coccidiostat supplier to include a colored iron particle tracer in its salinomycin premix (3). The feed manufacturer had made several manufacturing errors with salinomycin being included in adult turkey feeds with thousands of turkeys dieing as a result.

The feed manufacturer developed a testing program where its truckdrivers would test every load of turkey feed for the presence of the colored iron tracer as an indicator of the drug on a "real time" basis as the truck was loading.

The truckdriver would hope to find no colored tracer spots and would hold the feed for additional testing if he found more than 3 spots with 45 spots expected from a feed formulated with the medication. The feed manufacturer could tolerate 20% contamination of salinomycin but not more. Setting a tolerance of 3 tracer spots allowed the feed manufacturer to ship feeds with trace levels of contamination while stopping feeds that could be toxic to the adult turkeys.

This testing program included a requirement that a "control positive" feed be tested each day to be sure a feed formulated with salinomycin would yield a positive tracer test result. It also required setting "acceptance/rejection" criteria allowing a small amount of tracer (and drug) contamination when this would not be harmful.

The first use of a tracer on an industry wide basis to allow feed manufacturers to control a medicated feed occurred in 1987 when a major pharmaceutical company included colored iron particles in its Nicarbazin (4) premix. Nicarbazin while an excellent chemical coccidiostats will destroy shell egg quality if it reaches breeder feeds with one mistaken truckload of feed having the potential to cause an economic loss of USD $250,000 or more.

Before the use of the tracer in Nicarbazin, the pharmaceutical supplier of the drug had for some years provided feed manufacturers a chemical "quick test" for the drug in feeds. This test, however, suffered from several problems:

1. One of the reagents was highly flammable and could explode if heated.
2. Another reagent was DMSO (dimethylsulfoxide) that while not toxic itself could amplify the toxicity of other compounds if the DMSO was spilled and made skin contact with the individual running the test.
3. In the USA, the wastes from the test were considered "hazardous wastes" requiring special and expensive waste disposal.

The arguments supporting the use of the colored iron particles as a tracer for the Nicarbazin included:

1. Many feed manufacturers did not want to run the chemical "quick test".
2. Many feed manufacturers were so afraid of toxicity from the drug they would not formulate it in their feeds unless they could test for it on a "real time" basis.
3. The drug was an old product and this would give the marketer of the drug something new to talk about.

Initially, the tracer had little impact on the marketing and sales of Nicarbazin, however over the nearly 20 years since it was first included in the premix, nearly all users of the drug have adopted the tracer test and today virtually no one runs the old chemical "quick test". During the year 2002, more than 60,000 tests were run in the USA not only to prevent manufacturing errors that could lead to toxicity but also to prevent manufacturing errors where the drug might reach finisher feeds where its presence could lead to residues in poultry tissue and resulting condemnations.

b. Tracer use to prevent tissue residues in meat, poultry or fish

The first use of colored iron particles as tracers for this purpose was in 1988 in the coccidiostat halofuginone (5). This chemical coccidiostat for poultry is normally formulated at 3 grams/metric tonne of feed. However, the product is subject to several problems that make both the use of a tracer and the extensive testing of it in feed useful.

The problems with this coccidiostat were:

1. The assay of the drug in feeds is expensive and time consuming.
2. Chemical assays of feeds at the formulated level of 3ppm are not very accurate or reliable because feeds may contain many ingredients that may confuse the assay.
3. The chemical assay of poultry is excellent with a low detection limit, as the poultry meat provides a simple "matrix" to analyze.
4. The US Department of Agriculture at the time set a mandatory withdrawal time for the drug and a low tolerance for residues of the drug in poultry tissue.

The result of these problems was that the US Department of Agriculture was condemning poultry for having residues of the drug when at the same time the pharmaceutical company could not tell with certainty whether the drug was present or absent in the poultry feed provided to the affected birds.

Poultry integrations wanted to use the drug but would not unless the pharmaceutical company would provide a test for their withdrawal feeds to be reasonably certain the drug was not present at levels that could lead to tissue residues. The inclusion of colored iron particles in this medicated premix together with a well considered program for testing large numbers of feed samples for the tracer provided an answer to this problem. Many feed manufacturers would test samples of feed at the feedmill whenever they would start a run of finisher feed. Many would also have their farm managers test samples from all truckloads of finisher feed delivered to their farms.

Tracer Use To Identify Non-Medicated Feed Additives In Formula Feeds

While the greatest use for tracers in feeds is to identify medicated premixes, another major use is to code proprietary feed additives such as complexed minerals and enzyme products.

Footnotes:

4. *Nicarbazin is sold commercially as Nicarb (tm) manufactured by Phibro Animal Health, 710 Route 46 East, #401, Fairfield, N.J. 07004 USA.*
5. *Halofuginone is sold commercially as Stenorol (tm) and is available from Intervet,Inc. 405 State Street, Millsboro, N.J. 19966 USA.*

Here the use is primarily to assure patent and distribution rights are not infringed and that feed manufacturers include relatively expensive premixes when they are specified in feed formulations. The tracer also allows testing to confirm the feeds are completely mixed.

The chemical assays of final feeds for zinc methionine (6) are not specific. An unscrupulous feed manufacturer can gain an economic advantage by adding zinc oxide plus dl-methionine instead of the complexed mineral and it often will be impossible to detect the difference by chemical analysis of the final feed. An "exclusive" tracer used to mark the proprietary premix and feeds containing it allows detection of fraud or improper mixing.

If the proprietary premix is not added to feeds, the manufacturer of the premix suffers an economic loss but more importantly the feed customer loses efficacy and then determines wrongly the feed tracer helps assure honesty in the marketplace.

Tracer Use to Code Premixes and Feeds Containing Them as Proprietary

When an "exclusive" tracer is included in vitamin, mineral or feed additive premixes, it serves not only to mark the presence or absence of the premix in feeds but also it marks the premix and feeds containing it as proprietary. Sometimes this is the primary reason the tracer is included in the premix.

The feed manufacturer may take large numbers of samples and analyze them for the tracer as a screening technique for the coded premix. If tracer results from a feed sample are much lower or higher than expected, the feed manufacturer can analyze the sample for the active ingredient. In this way, the feed manufacturer can ensure that complaints from commercial customers are legitimate, that proprietary feeds are not being misused (as with contract growers in the poultry industry) and that feed is properly manufactured.

c. Tracer use today for continuous quality assurance of formula feeds

Canada is an example of a country where tracers are widely used today. Currently, eleven different colored iron particle tracers are routinely used in premixes and feeds containing them. Every feedmill has detection apparatus for these tracers and many run thousands of tracer tests each year to be certain feeds contain formulated premixes and do not contain premixes where they may be harmful.

The major medicated premix suppliers have provided "Colour Cards" to the feedmills so the feedmill personnel can correctly identify different tracers that may be present in their feeds. The feed manufacturers keep the tracer test paper with retain samples of each truckload of feed as proof the test was run with acceptable results.

While "on the spot" testing by truckdrivers is primarily qualitative, the various tracers can be quantified to estimate the level of coded premix +/-30%, as good as many chemical assays for active ingredients.

The tracer test becomes quantitative when the feed manufacturer sets a standard of 3 permitted spots maximum in a feed sample of 500 grams when a feed formulated with the premix would contain on average 45 spots. In this way, if 10% cross-contamination of the medication into a non-medicated feed is safe, it can be shipped based upon the tracer test results.

The tracer test can also be used when physical inventories of medicated premixes do not reconcile at the end of a day. Inventory control is the primary mechanism used at feedmills to confirm drugs are used properly in manufacturing feeds. What can a manufacturer do, however, when physical inventories do not reconcile at the end of the day? Must the manufacturer recall all feeds manufactured that day? When tracers are formulated in medicated feeds, if retain samples from each truckload of feed have been kept, the feed manufacturer can analyze 100 or more such samples in 2 or 3 hours to locate where the error occurred. Feed can be tested on farms also if necessary.

Footnotes:

6. Zinc methionine is sold commercially as Zinpro 100 and is available from Zinpro Corporation, 6500 City West Parkway, Suite 300, Eden Prairie, Minn. 55344 USA.

d. Future directions in tracer use for continuous quality assurance of feeds

Today in Europe, meat and bone meal is not permitted in any feed and is being incinerated with an economic loss of possibly USD $1.5 billion/year. The problem is government regulators are afraid ruminant by-product if permitted in any feed will reach ruminant feeds where it can transmit mad cow disease and represent a risk to human health.

Proposals have been made to require one or more tracers in meat and bone meal so such product can be detected "on the spot" in ruminant feeds where it could be harmful. Ideally, 200 or 300 tracers may be required, one for each plant manufacturing such product.

Already, certain iron based tracers formulated in feed additives can be detected in animal feces. This makes it possible to know whether the animal was fed a proprietary premix or feed immediately before slaughter.

More feed manufacturers may also want "exclusive" tracers to code their feeds as proprietary to ensure full "traceability". This can help satisfy the public interest that everything reasonable is being done to assure the safety of the food supply.

Table 1. Colored Iron Particle Counts From 48 Pelleted Feed Samples – "Retain Samples"

From Truckloads of Feeds- Two Formulated With Nicarbazin With Tracer 46 Supposed to Contain No Nicarbazin or Tracer.

Sample Code	Weight	Tracer Count	Sample Code	Weight Count	Tracer
301-Nicarb	402 gms	41	302- S	480 gm	0
302- No Nicarb	533 "	0	302-S	473 "	0
302-	547 "	0	302-	502 "	0
302-	502 "	0	302-	520 "	0
302-	548 "	0	302-93308	520 "	0
302-	567 "	0	303-971	404 "	0
303- No Nicarb	512 "	0	2441-	502 "	0
303-	544 "	0	301- Nicarb	462 "	38
303-	520 "	0	303-	492 "	0
303-	396 "	0	303-	538 "	0
303-	509 "	0	303-	523 "	0
302-	481 "	0			
302-	521 "	0			
302-	421 "	0			
302-	496 "	0			
302-	526 "	1			
302-	371 "	0			
302-	388 "	0			
302-	480 "	1			
302-	515 "	0			
302-	463 "	0			
303-	392 "	0			
303-	518 "	0			
303-	518 "	0			
303-	520 "	0			
303-	470 "	0			
303-	530 "	0			
303-	514 "	0			
92363TT	452 "	0			
93254TT	489 "	0			
93255TT	496 "	0			
93257TT	518 "	0			
93262TT	432 "	0			
93186TS	355 "	0			
302-7V	325 "	0			
302-	536 "	0			

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The Benefits Of Feedmill Automation

Willie Unger
Comco Manufacturing
Canada

Introduction

Automation was once considered to be a "luxury item" in the feed industry. It was an easy way to control facility equipment as well as providing batching and weighing functionality. There were minimal interlocking capabilities and minimal security was required.

Today's feed industry has demanded that automation provide a way to increase production, accuracy and quality of products while decreasing mistakes, labor and waste. Issues such as BSE, Avian Flu and cross contamination issues have amplified the need for product tracking, increased documentation and data analyzing.

Automation systems now pay for themselves through the benefits they provide and have become a necessary tool for this competitive market.

"A company that has a system in place that documents how it operates and what it does to produce safe feed or food, that strives for continuous improvement and so on will have an advantage when it comes to meeting the ever-changing and more stringent requirements of its customers". *Feedstuffs Issue Date: April 4, 2005 | Issue 14 | Vol. 77 By Michael Howie.*

The Automated Solution

Following are some components that should be included within automation systems to provide maximum benefits to the customer:

1. Ease of Use
2. Traceability and Movement Displays
3. Cross Contamination
4. Audit Trails
5. Trending
6. Maintenance
7. Documentation, Reports and Data Analysis

Ease of Use

Today's automation systems are very user friendly. Standard PCs are used so that they can be easily replaced and upgraded. Within a short period of time operators can learn the automation systems and run their facilities with maximum efficiency. Having weights and other process readings displayed within one central location also saves the operators from having to double check all of the equipment before starting a new run. Having a centralized location also allows operators to complete many tasks at one time. An example of this is one PC is controlling pelleting while another is receiving raw ingredients or out loading product.

Electric devices and sensors within the plant maximize automation. For example, main bulk bin gates can close when bins have reached high levels or secondary bins can be lined up as the next automatic destination.

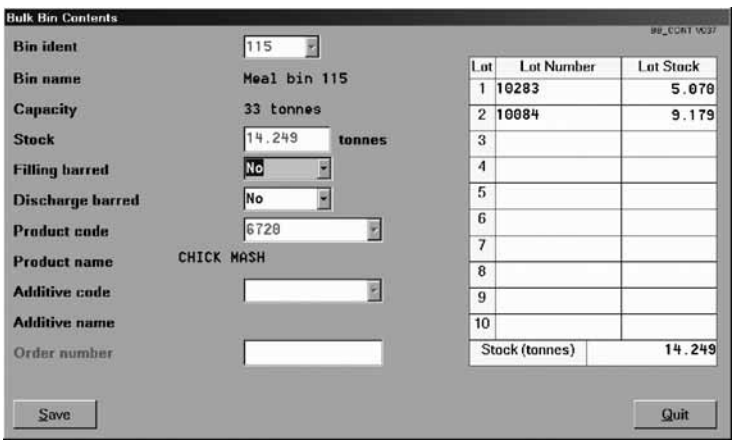
New technologies such as the wireless/remote hand held PDA allow operators to be mobile within a facility and continue to respond to alarms and other issues.

- Receiving ingredients while standing in the load out bay
- Transferring product throughout the feed mill from outside the operator's control room
- Standing beside a piece of equipment and starting and stopping it for maintenance purposes.
- View and Acknowledging alarms
- View production schedule
- Monitor and adjust parameters
- Monitor and override any item
- View and update raw material bin stock
- View and update finished product bins
- View and acknowledge hand additives

Any number of base stations may be located around the site to provide coverage.

Traceability and Movement Displays

Traceability provides a means for tracking raw materials and/or finished products whether in bulk bins or bags. Some materials, e.g. premixes may need to be tracked whereas other materials, e.g. bulk materials, may not need to be.



Traceability can be accomplished by tracking lot numbers and/or bar codes. Bar codes can be developed through the automation system if there is not one readily available.

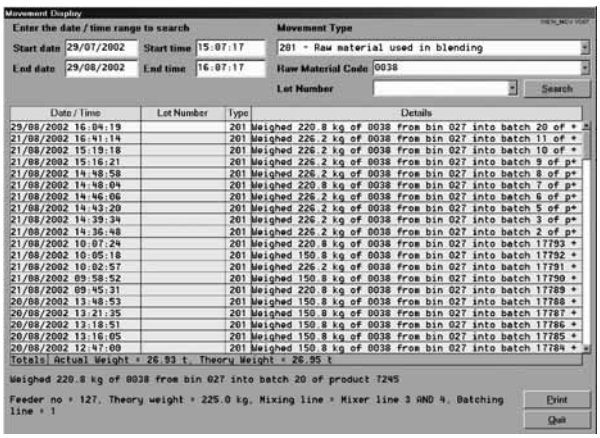
Barcodes contain the following information: -

- Raw material code
- Batch number (lot number)
- Supplier code
- Expiry date
- Weight

Benefits of Bar Codes:

- Checks the correct material is about to be added.
- Checks the correct weight is added.
- Checks the material has not expired
- Logs the batch number with the rest of the batch and then onto the long-term archive.

Movement Displays allow you to investigate anywhere material is used or moved.



Here we have asked for details of all weighing of material 0038 (ground corn) in the past month.

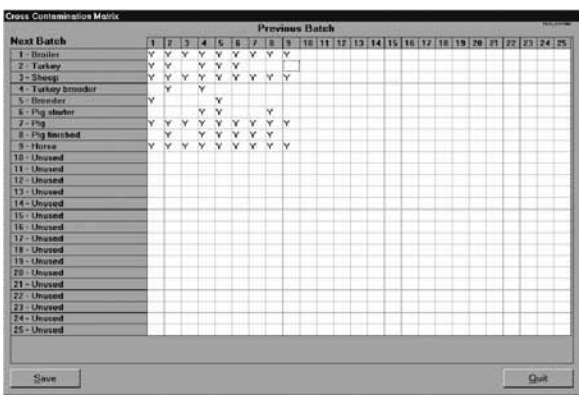
Cross Contamination

Automation systems should be configured to prevent cross contamination where one batch is following another. In this instance, a product parameter specifies the cross contamination group number between 0 and 64. A number of 0 signifies that the batch is neither susceptible to nor generates any contamination (in effect, it operates as a flushing batch). A minimum of 25 x 25 matrix then shows which product groups are allowed to follow which other groups. This matrix is user configurable.

In addition, each raw material holds two selectable levels. Each of these can have 64 more cross contamination groups, which are utilized if the inclusion level of the material is over the set amount.

Cross contamination checks are made in 3 areas: -

1. Down the mixer line (or each line if more than one)
2. Down each production line (e.g. pellet line)
3. For any item (e.g. elevator, bin, etc.) which has been selected for checking.



Example cross contamination matrix

Materials over a certain inclusion level can affect the cross contamination groups. This gives the greatest flexibility in reducing cross contamination.

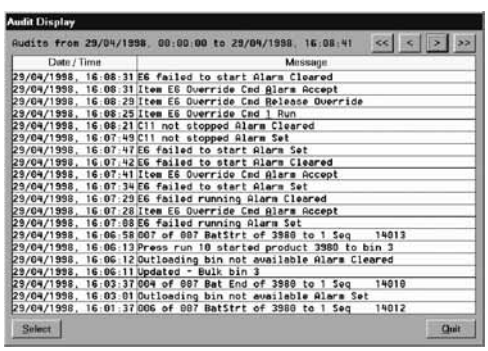
If the production schedule contains a batch, which is prevented from following the previous batch, then an alarm is generated and the batch not blended. A different batch or a flushing batch may be produced instead. There are override options (password protected) available for each of the three areas.

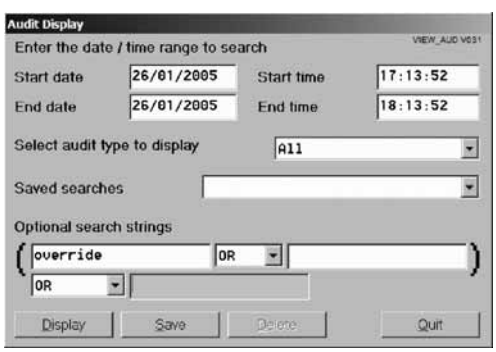
The cross contamination code specifies which product types can follow others. Material inclusion levels can also add extra codes.

Audit Trails

Actions logged to the audit trail include but are not limited to: -

- Alarms Set and Clear
- Operator acknowledging an alarm
- Batch Start and End
- Intake starting and cleaning out
- Silo transfer starting and cleaning out
- Pre-grinder route starting and cleaning out
- Changing a raw material or meal bin contents & stock
- Changing materials / formulas / products
- Override cross contamination
- Use of bin substitution and standard substitutions
- Manual override enable
- Manual override of plant items
- Pellet run starting and cleaning out (includes details of downstream liquids)
- Changing finished product contents/stock
- Batch override operations
- Scale calibration
- Bulk out loading operation
- Any other significant events





Each detail of the feed mill is logged to the database and can be retrieved. Operators should be able to search for particular audits. In this example there is a facility to search on 3 different texts and to store these searches.

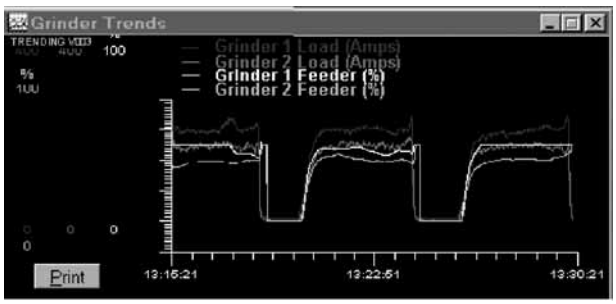
System screen shots are developed by Comco for AutoPilot4Feed control systems

Trending

Automation systems should provide the benefits of powerful trending package. A trend is a moving graph on the screen showing the past xx minutes of the important variables. Typically, these may include pellet current (Amps), temperature, feeder speed etc.

The trends run in real-time and typically show the past 15 minutes readings of a number of variables.

Any analogue (process value) may be trended. Examples of this are: pellet temperature, conditioner temperature, pellet mill amps, etc…



Example trend window

Thus at a glance, the operator can see what has happened over the past 15 minutes. This is especially useful if the operator has been away for a while, for example while changing a die. In practice, operators tend to only look at the trends under normal running.

Maintenance

Equipment that is properly maintained is crucial in working towards an efficient facility. Modern maintenance programs that are integrated into automation systems allow operators and facility staff to view real-time equipment usage information on which to base their preventative maintenance programs.

- Downtime is lost money
- Optimum equipment performance increases productivity
- Improve manpower utilization
- Less overtime = Less stress
- Extend equipment life

Documentation, Reports and Data Analysis

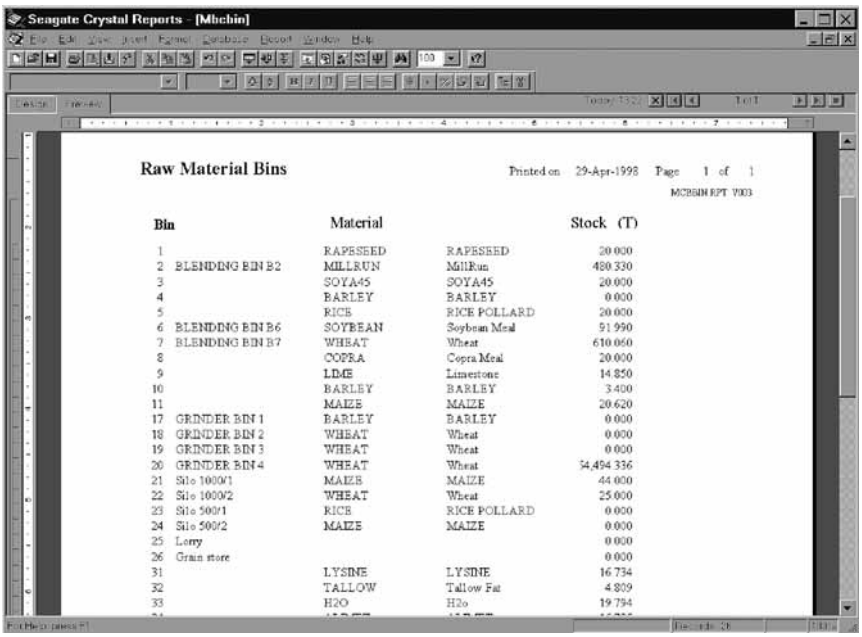
An automation system that can log important data to a database is essential when developing a fully documented facility. Open databases (ODBC) allow data to be exported into other programs to be analyzed and manipulated. Formatting data into reports is also essential for tracking information over time to increase efficiencies.

All reports and printouts should allow flexibility to be manipulated. All databases should be ODBC compliant. All data should be available for viewing, printing or writing to a file.

Some Sample Reports Provided / Supplied include but are not limited to:

- Raw material usage
  - last month
  - yesterday
  - last month
  - last week
  - yesterday
- Production log
- Summary of batches produced between 2 dates
- Full batch report
- Short batch report
- Raw materials
- Raw material bin / tank / silo contents
- Formula raw material explosion
- Audit report (includes management, batch information, and alarms set and clear)

- Selected product
- Selected formula
- Pellet run summary – graph and 30 second details
- I/O and item configuration
- Pellet die report
- Hand additives report for yesterday
- Alarm summary and frequency report
- Standard substitutions stored
- Raw material contracts
- Feeder report
- Bin filling report
- Search for a raw material
- Silo transfer report
- Bin / silo inspection
- Warehouse, rework and medicated stock report



As an example, Crystal Reports (or equivalent) may be used to generate files which may then be transferred to another computer or further analyzed using other software packages such as spreadsheets, graphing packages, etc.

Specific Feedmill Regions

Today a complete integrated system can include the following feed mill regions with full automation:

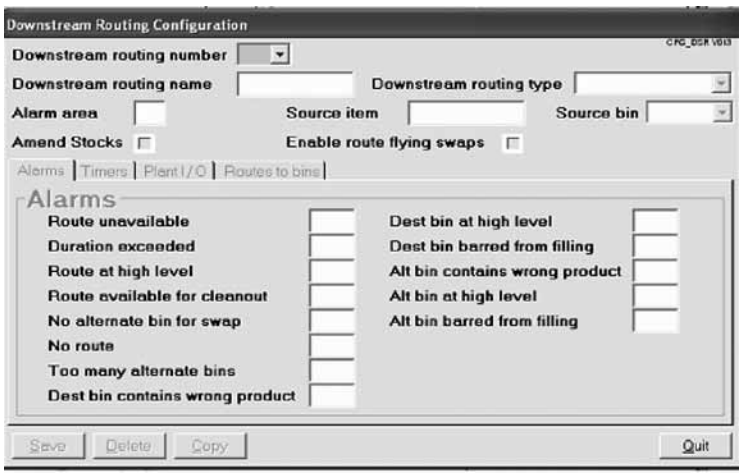
- Truck Scale
- Receiving
- Grinding
- Batching
- Hand additions (with bar-coding)
- Mixing with liquids control
- Pellet control
- Cooler control
- Downstream control (Routing)

- Fats coater control with enzyme
- Load-out

Multi-Species Separation Control

Routing

Ccontrolling routes from one set of raw material bins to another set of raw material bins or from a set of finished product bins to another set of finished product bins. Examples would be silo to blending bin or grinding in a pre-grind feed mill.



HACCP- Hazard Analysis and Critical Control Points

A management system in which food safety is addressed through the analysis and control of biological, chemical, and physical hazards from raw material production, procurement and handling, to manufacturing, distribution and consumption of the finished product.

HACCP involves seven principles:

1. **Analyze hazards.** Potential hazards associated with a food and measures to control those hazards are identified. The hazard could be biological, such as a microbe; chemical, such as a toxin; or physical, such as ground glass or metal fragments.

2. **Identify critical control points.** These are points in a food's production--from its raw state through processing and shipping to consumption by the consumer--at which the potential hazard can be controlled or eliminated. Examples are cooking, cooling, packaging, and metal detection.

3. **Establish preventive measures with critical limits for each control point.** For a cooked food, for example, this might include setting the minimum cooking temperature and time required to ensure the elimination of any harmful microbes.

4. **Establish procedures to monitor the critical control points.** Such procedures might include determining how and by whom cooking time and temperature should be monitored.

5. **Establish corrective actions to be taken when monitoring shows that a critical limit has not been met**--for example, reprocessing or disposing of food if the minimum cooking temperature is not met.

6. **Establish procedures to verify that the system is working properly**--for example, testing time-and-temperature recording devices to verify that a cooking unit is working properly.

7. **Establish effective record keeping to document the HACCP system.** This would include records of hazards and their control methods, the monitoring of safety requirements and action taken to correct potential problems. Each of these principles must be backed by sound scientific knowledge: for example, published microbiological studies on time and temperature factors for controlling foodborne pathogens.

Summary

Feed milling has become more complex than ever. Due to this complexity, more automation tools are required to make your facility compliant. When working towards an automation solution take the time that is necessary in selecting a vendor that is capable of meeting the needs of today's demanding industry.

References

Feedstuffs Issue Date: April 4, 2005 | Issue 14 | Vol. 77 By Michael Howie.
System screen shots are developed by Comco/DSL for AutoPilot4Feed control systems.

Sampling Equipment For Raw Materials And Finished Feeds

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Ingredient quality is the foundation on which an animal ration is built. Correct sampling and sample evaluation enables the processor to make inferences about the quality of incoming grain, protein sources, micronutrients, and finished feed.

Prior knowledge, based on ingredient data, allows assignment of the appropriate sampling pattern and sample size to different feed ingredients. This sampling pattern depends on the dimensions of shipment containers, conveying equipment, and sampling equipment.

Thus, a sampling program should be a dynamic process in which a company is always striving to achieve the greatest possible inference about different feed ingredients and finished feed at the lowest possible cost.

Definitions

To facilitate a discussion of sampling, definitions of the different types of samples are presented below (Pierce, 1994):

Check sample: A sample that is carefully subdivided with portions sent to a number of laboratories for analysis and used as a check on laboratory assay procedures.

Composite sample: A sample formed by compositing or accumulating and combining a number of discrete samples; useful in determining the average composition of a large amount, such as a shipload, carload, or truckload.

Discrete Sample: A sample representing a specific, usually small, amount of material. It also is known as an individual spot or grab sample and is useful in determining variations within a lot, adequacy of mixing, and other attributes that may vary throughout a larger amount of product or ingredient.

Duplicate Sample: A representative portion of an existing sample that is then provided to an additional laboratory and often used to resolve differences between laboratories.

Official Sample: One taken by a government official, either for regulatory purposes or to assign an official grade.

Purchasing Sample: A portion submitted by the supplier to a purchaser, purported to represent a lot offered for sale.

Referee Sample: A sample taken, often by an impartial sampler, and submitted to a referee laboratory for the purpose of arriving at a settlement between buyer and seller.

Reference Sample: A sample of known characteristics kept as a guide or comparison check for incoming ingredients and finished product. The reference sample may be used for visual comparison (e.g., color, texture).

Retained Sample: A duplicate portion of a lot retained in case an analysis is needed following use or distribution of the lot.

Standard Sample: One that has been carefully analyzed by experienced laboratories and provided to other laboratories as a means of standardizing or calibrating their methods or instruments.

Working Sample: The portion or portions of a sample used for analysis.

Sampling Schemes

Common sampling schemes used in the feed and grain industry include simple random sampling, stratified random sampling, and systematic sampling.

A simple random sampling from a population of N sampling units gives equal probability to all units.

A stratified random sample is obtained by separating the population elements into non-overlapping groups, called strata. Then, a simple random sample is collected from each stratum. This typically is how shiploads are sampled – each hold represents a stratum and multiple samples are collected randomly within each hold.

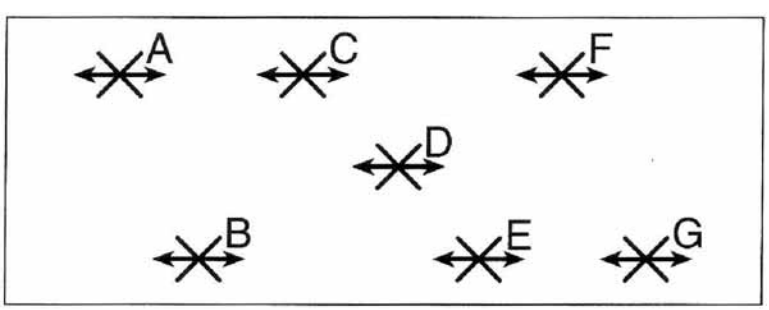
A systematic sample involves random selection of one unit, and then repeated collection of sampling units at equal intervals thereafter. Systematic samples are easier to perform than a simple random sample and often provide greater information per unit cost than does simple random sampling. A diverter-type (D/T) mechanical sample is an example of a systematic sampling system. The D/T is mounted in grain spouts, at the end of belts, or at the head of elevator legs, and the diverter moves through the grain (takes a cut) at timed intervals.

The feed industry uses a combination of these types of sampling schemes. Instructions for collecting an official sample of grain (GIPSA, 1995) are listed in Table 1, and depicted in Figure 1. Bulk truck or rail shipments of grain or soybean meal are frequently sampled using a hand probe and employ a sampling pattern (Figure 1).

Table 1. The Grain Inspection, Processors, and Stockyard Administration Sampling Pattern that Stratifies Flat-Bottom Trucks or Trailers for Hand Probe Sample Collection

Site A	Probe the grain approximately 2 feet (0.6 m) from the front and side.
Site B	Probe approximately halfway between the front and center, 2 feet (0.6 m) from the side.
Site C	Probe approximately 3/4 of the distance between the front and center of the truck, 2 feet (0.6 m) from the side.
Site D	Probe grain in the center of the carrier.
Sites E, F, G	Follow a similar pattern described above for Sites A,B,C for the back half of the carrier.

Figure 1. Sampling Pattern for Bulk Carriers of Grain



The prescribed procedure sampling soybean meal at vessel loading facilities, defined by the National Oilseed Processors Association (NOPA), conforms to a systematic sampling design (Table 2).

Table 2. NOPA Procedures for Sampling Soybean Meal at Vessel Loading Facilities

A. Sampling of soybean meal shall be done by an automatic mechanical sampler located in a spout or at the discharge of a belt conveyor, as appropriate. The sampler shall be designed to cut an increment from the entire cross-section of the meal stream, perpendicular to the flow, at a location where the meal is flowing freely and at a uniform rate, in order to obtain the most representative sample of the meal flow. If the sampler is located in a spout, the spout slope must be 45 degrees or more from horizontal, and the flow must not be choked. When the diverter, or pelican, is stationary between cuts on either side of the meal stream, the opening shall be sealed to prevent dust from entering.

B. The sampler system shall be located at a point beyond which no blending or addition to the product may be introduced prior to its being loaded onto the vessel.

C. The activation of the sampler shall be regulated by an adjustable timer. When the average meal-flow rate through the sampler is less than 800 tons per hour, a sample, or cut, shall be taken for every 5 tons or less of meal flow. When the flow rate is between 800 and 1,200 tons per hour, a sample shall be taken for every 8 tons or less of meal flow. When the flow rate is 1,200 tons per hour or greater, a sample shall be taken for every 12 tons or less of meal flow.
A minimum of 10 samples shall be taken during the loading of any one vessel.

D. The diverter opening for cross-cut samplers and swing-type samples in which the diverter moves about a horizontal shaft (where the entire length of the diverter opening passes through the stream at the same speed) shall be of uniform width in the range of 8mm to 22mm. For rotary-type samples, in which the diverter moves about a vertical shaft and passes through the stream similar to a swinging door (with the outer end of the diverter moving at a higher speed than the inner end), the diverter opening width shall be a minimum of 8mm at the end nearest the pivot, and shall increase in width in proportion to the distance from the pivot point. In all cases, the diverter shall cut the meal stream at an average speed of approximately 30 meters per minute.

E. The sample taken by the automatic sampler may be reduced in size by one or more mechanical dividers, but the reduced sample must still be representative of the meal passing the sampler. The accuracy of the divider shall be equal in performance to a Jones or Boerner type divider. To comply with contract specifications, the entire sample may be further reduced through a Jones or Boerner divider or its equivalent. Then each portion of the sample must be placed in an official NOPA soybean meal sample bag.

Bagged shipments of basemix, premix, and medicated feed articles should be sampled with a bag probe using procedures outlined in Table 3.

Table 3. Procedures for Collecting Bagged Ingredients Samples

1. Stand the sacks up on end and insert the probe into the top corner of the sack.
2. Move the probe diagonally through the sack until the end of the probe touches the bottom corner opposite the top corner and withdraw sample.
3. For shipments of one to 10 bags, sample all bags; for shipments of 11 or more, sample 10 bags selected at random; for shipments less than five bags, collect at least five probes to gather enough material to perform an assay and retain a sample.

Drums or **barrels** of **liquid ingredients** such as fat or molasses can be sampled using a tube of glass or stainless steel, 10mm to 12.5mm in diameter and several feet long, referred to as a drum thief. Sample at least 10 percent of the containers and collect a minimum of 500 g. Bulk shipments of liquid ingredients may be sampled using a bomb sampler or core sampler. In all cases, liquid ingredients should be subject to some stirring action (e.g., rolling drums) prior to sampling to ensure ingredient distribution.

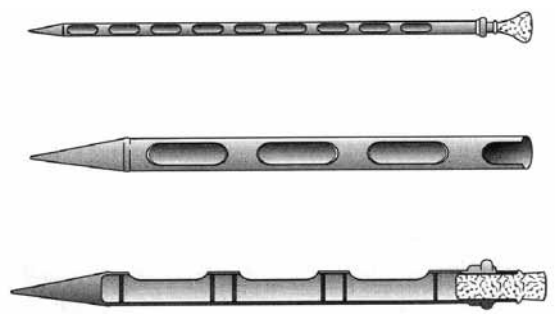
Finished feed can be sampled as it is transferred to the delivery vehicle if feed is in bulk form. In the case of cattle feed that is mixed during transport, collecting the sample from the feed bunk is an acceptable practice.

Collecting feed samples from portable grinder-mixers during discharge into bulk feeders is a recommended practice, particularly when evaluating mixer uniformity.

Sampling Equipment

Slotted grain probes may be used to collect a representative sample from grain, soybean meal, or finished feed. The grain probe should be long enough to penetrate at least 3/4 of the depth of the feedstuff. Official grain samples are collected using a 3 cm diameter probe that consists of two tubes, one inside the other (Figure 2). The inner tube is divide into compartments that enable the individual collecting the sample to detect inconsistencies in grain quality across the profile (depth) of the carrier. This procedure is more labor-intensive since the contents of the probe must be emptied onto a tarp or trough and inspected before the grain is transferred into a container.

Figure 2. Grain Probes



The probe should be inserted into the grain or feed ingredient at a 10-degree angle from the vertical, with the slots facing upward and completely closed. A 10-degree angle is used to obtain a cross-section of material, while placing the end of the probe as close to the bottom of the carrier as possible. The slots must be kept closed until the probe is inserted as far as it will go. If the probe's slots are open as it enters the grain, a disproportionate amount of material from the top will fill the probe.

After the probe is fully inserted, open the slots and move the probe up and down quickly in two short motions. Close the slots completely, grasp the probe by the outer tube, and withdraw it from the grain.

Tapered bag triers are constructed of stainless steel and are characterized by a sharp point, a tapered body, and an open throat. These triers are available in lengths from 15 to 30 cm long Tapered bag triers are used to sample closed bags of powdered and granular commodities.

Bomb or **zone** samples are used to collect liquid ingredients from bulk carriers. These samplers consist of a closed cylinder ranging in size from 30 cm long by 4.5 cm in diameter to 40 cm long by 8 cm in diameter; with capacities of 100 g and 1 Kg, respectively (Anonymous, 2000).

A valve lifts when the bottom of the tank is reached, or it can be manually lifted by a cord attached to the valves's plunger if intermediate depths are sampled.

Sample Reduction

The contents of each probe location should be mixed together prior to reducing the sample. Sample reduction may be performed using a riffler, Boerner Divider, or by quartering the sample. The end result of this process should produce a working sample of 0.5 to 1 Kg and a retained sample that should be kept for a predetermined time (usually until the meat animal is marketed and processed).

Complete feed and feed ingredients may be partitioned into uniform subsamples using a **riffler**. The sample is poured into the hopper, which is divided into equal portions by two series of chutes that discharge alternately in opposite directions into separate pans (Anonymous, 2000).

The **Boerner Divider** is the grain industry's standard for splitting samples. A sample of grain is placed in the hopper and then released down a cone, where grain is cut into 38 separate streams, which rejoin into two streams and then empties into the pans (Anonymous, 2000).

Quartering is a method for reducing the sample size of high-roughage feed (e.g., cattle feed) to a convenient amount for analysis. Spread the mixed composite sample on clean plastic or paper to form an even layer. Mark into quarters. Take two opposite quarters, mix, and repeat until the two quarters selected give the desired sample size.

Heavy plastic bags, zip-lock bags, or plastic containers with lids make excellent sample containers for dry ingredients or finished feed. Label samples as they are taken, identifying the date, sample number, and the contents (or ingredient to assay). Preservation of samples is highly important. Immediately freeze high-moisture feedstuffs, silage, or green forage. Store other materials in cool, dry locations.

Sampling Frequency and Retention

How often should **incoming ingredients** be sampled? With few exceptions, all ingredients should be sampled upon arrival and inspected for identity, physical purity, and compared with a reference sample. These samples, at a minimum, should be retained until the complete feed has been consumed by the animal and performed according to the label.

Commercial feed mills should collect and retain a sample of **complete feed** for each run of a given product. The sample should be retained as long as potential liability exists (e.g., until the meat animal is marketed and processed).

Medicated feed sampling and evaluation must conform to regulatory requirements. In the United States, the Food and Drug Administration (Herrman and Stokka, 2000) requires feed mills licensed to utilize high-potency drugs that have a withdrawal period (Category II Type A) to perform routine assays. Three representative samples of medicated feed containing each drug or drug combination used shall be collected and assayed by approved official methods every year.

Receiving Procedures

All feed processors should develop and follow a set of procedures for receiving feed ingredients. This should include inspection of the carrier's paperwork to ensure the correct material is on the carrier, a sensory inspection of ingredients collected from the sampling process, and documentation of receipt of those ingredients.

When receiving bulk material, inspect the shipping documents for ingredient identification, mill and supplier, and name of the individual hauling the cargo. Inspect the ingredient label and compare to previous labels. If no label accompanies the feed ingredients (with the exception of grain), do not unload the carrier until a label can be supplied. Check the label for the correct ingredient and analyses guarantees.

Ingredients should be examined for sensory characteristics (color, odor, texture, insect infestation, and moisture). This inspection procedure should be compared to reference samples or pre-established standards for comparison purposes. Do not unload ingredients that do not pass this initial inspection; particularly with bulk ingredients. Once the material is unloaded, you own it.

A receiving report that documents receipt of ingredients will augment a sampling program. This report should include the date, ingredient name, supplier, carrier name, license, bill of lading, purchase order or invoice number, time received, weight, bin number where the ingredient was placed, sensory or physical qualities, and signature of the individual who unloads the material (Figure 3).

Figure 3. Receiving Report

Receiving Report		
Date Received	Date Unloaded	
Commodity		
Shipper's Name		
Truck Name		
Trailer No.	P O No.	Bill of Lading
Weight Ticket No.	Net Weight	
Bin No.		
Time In		
Time Out		
Unloaded By		
PHYSICAL QUALITIES Color_____ Odor _____ Texture _____ Moisture _____ Insects _____ Sample No. Assigned_____		
Remarks		

Figure 4. Case Report Form

Date Report Prepared _____
Owner's Name_____
Address _____
City _____State_____Zip_____

Report Prepared By _____
Address _____
Telephone Number _____

If a company's product is in question, have they been notified? ❒ Yes ❒ No
Date notified_____
Veterinarian's or fieldman's report is attached? ❒ Yes ❒ No
Date called _____

Sample Identification: (give each sample a number or letter) _____
_____
_____
_____

Description of Case: (see suggested list of case information)
Class of Livestock _____Number _____Age_____Sex_____
Raised on Farm _____If Purchased, When _____Where _____
Describe symptoms in detail and date first noticed _____
_____
_____
_____
Describe ration in detail and method of feeding. Include all changes made recently_____
_____
_____
_____
Dates and details on every drug, vitamin, antibiotic, hormone, wormer, insecticide, vaccinations, disease-preventive shots or disease treatment used on livestock. Include castrations, dehorning, etc.
_____
_____
_____
List any contact livestock could have had with poisons (refuse, trash pile, fertilizer sacks, paint cans, weed sprays, insect sprays, etc.). Any toxic weeds?
_____
_____
_____
Weather conditions, especially sudden changes in preceding two weeks _____
Water supply checked for nitrates? _____for salinity? _____for potability? _____
Readily available to livestock?
Describe housing, lots and management problems_____
_____
_____
_____
Other pertinent information _____
_____
_____
_____
I declare that to the best of my knowledge this is a true, complete and correct report.

Signature of Livestock Owner_____

Procedures for evaluating physical (test weight, bulk density, foreign material) and nutritional properties of feed ingredients are described in Kansas State University Research and Extension publication MF-2037. (www.oznet.ksu.ede/library/grsci2/).

Sampling for Livestock Health Problems

Proper treatment of a livestock problem depends on correct identification of the causative agent. A carefully compiled history will usually provide an adequate background for immediate and practical emergency treatment. A correct diagnosis of the caustic agent usually rests upon sample assays of feed, water, surrounding environment, or animal tissue and body fluids.

A case report form (Figure 4) lists important pieces of information to collect when livestock health problems occur (Wilcox, 1972).

Summary

Sampling is a critical part of any quality-assurance program. Steps involved with collecting a representative sample include following a sampling scheme; collecting enough sample to ensure it is representative; using the correct sampling equipment and procedure; inspecting the sample for its sensory characteristics; reducing the sample and preparing it for shipment, retention, or both; incorporating sampling into a structured method for receiving ingredients; sampling finished feed; and using sampling as a tool to help diagnose animal health problems.

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HACCP And Good Manufacturing Practice In The Feedmill

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Introduction

Throughout the world, consumers are becoming much more concerned with quality, appearance, taste, nutritional value and ethical values in regard to food. They expect food to be produced and processed according to good farming practices, and with greater respect to the welfare of the animals and the environment. They expect clear information about the product, its origin and method of production in order to make informed decisions on which products to buy. Most importantly they want food safety to be the number one priority for companies involved in the food chain.

The selection of raw materials and additives for animal feed has traditionally been based on a self-regulatory basis. The feed industry has used predominantly vegetable products and by-products for energy and protein, supplemented with animal by-products from the rendering industry and the feed could be manufactured at either single or multi species feed mills. In addition, a wide range of feed additives, ranging from antibiotic growth promoters to coccidiostats, was available for selection to optimize feed efficiency and growth. In the past ten years however, the advent of BSE, other feed related food scares and environmental issues has significantly changed the basis on which we select raw materials and additives due to a combination of government legislation and global pressure from supermarkets, international food companies such as McDonalds and KFC and consumers. In many countries the feed industry now has to consider selection of feed ingredients not just based on proven hazards but on acceptance to consumers based on perceived risks. These changes in consumer requirements are having a profound effect on the animal feed industry throughout the world.

Quality Control And Quality Assurance

The feed industry has traditionally relied on quality control to cope with quality standards. Quality control is the evaluation/testing of a final product prior to its dispatch from the mill, i.e. it is based on quality checks at the end of the production run that categorize the product as either standard quality or below standard quality or in some cases "non-marketable". Since, at the end of the production run, there is no way to correct production failures or upgrade the quality of the final product, the low-quality products end up being sold and therefore often result in customer complaints and the non-marketable products have to be reworked. Their production costs, however, are as high as those of the standard quality products. Thus, quality control has only a limited potential to increase the quality and efficiency of a multi-step production process such as feed manufacture. However, the need to produce and sell high quality feed and increase the efficiency of the production process has led to the development of quality assurance systems.

Quality Assurance, in contrast to quality control, is the implementation of quality checks and procedures to immediately correct any failure and mistake that is able to reduce the quality of the interim products at every step of the production process. A good example of quality control versus quality assurance within the mill is the difference between testing of feed for residues, which is quality control, and the implementation of residue avoiding production procedures within the mill which is quality assurance. In other words, quality assurance is all about the ability to prove what you do in the context of quality and food safety.

Quality Management

Quality Management systems have been part of the feed industry for a long time and have been independently accredited under the ISO 9000 series. ISO is a globally recognised set of standards

that assists manufacturers and their staff to operate in a systematic fashion to constantly maintain a high standard. Many feed companies in S E Asia are registered to ISO 9001. Whilst this imposes certain disciplines and conveys a commitment to quality assurance, it does not in itself guarantee the production of high quality feed or safe feed. One of the criticisms of ISO 9001 was that the operating company set their own quality standards, and provided these are maintained to a defined degree of consistency, registration would be granted. Another major criticism of ISO 9001 was that it did not address the issue of due diligence and risk assessment. As a result, despite ISO 9001 registration, the feed industry throughout the world has been associated with a range of food scares from BSE and Salmonella to Dioxin and drug residues. In 2000, ISO 9001 underwent a major revision. The ISO 9001:2000 standard now focuses closely on meeting the customers' needs and expectations as well as the requirement for continual improvement of the implemented quality management system.

Good Manufacturing Practices

Food safety concerns have led the feed industry to review their quality systems and differentiate between product quality, e.g. physical quality, nutritional content, and product safety, e.g. residues, pathogens etc. This review has led to the widespread implementation of Good Manufacturing Practices (GMP). GMP is a combination of written manufacturing procedures or operating procedures (OP's) which are aimed in particular at hygiene. The procedures are laid down by the industry and are designed to ensure products are of constant quality and safe to use. The procedures should cover the whole process from design and sourcing of materials to delivery of the finished product to the customer. The focal points are the management of medicines and additives, the control of undesirable substances and ensuring hygiene and safety. GMP fits under the umbrella of ISO programmes but in its breadth of scope, provides a guideline for the complete supply chain.

GMP usually consists of a code of practice that provides detail of the tasks to be carried out and the performance targets that should be achieved. The details of the code may vary according to the requirements of the supplier and the recipients but the details are accessible and may be subject to internal or external audit. Clearly, GMP is a useful means of moving an industry consisting of many suppliers towards a common standard. In Europe, Australia and South Africa, the feed manufacturing industry has implemented its own code of practice based on GMP which will be independently audited to the standards EN45011. In other parts of the world, such as Thailand, the government set and audit GMP for the feed industry.

For the feed industry the scope of the GMP should include:

- Design and maintenance of plant
- Source and quality of feed materials
- Manufacturing
- Storage of raw materials and finished products
- Loading, transport and delivery
- Quality Control
- Complaints
- Product Recall
- Personnel and training
- Documentation and traceability

It is important that the scope includes sourcing quality raw materials, which have been stored in audited storage facilities, transport of the raw material to the feedmill for the manufacture of animal feed and also the transport of the feed from the mill to the farm. Special provision must also be made for the manufacture of vitamin / mineral premixes.

Both GMP and QM systems work on the basis that if the job is done according to the codes or operating procedures food safety risk will be reduced. However, they often fail to allow changes to a process in response to variations in conditions and they tend to assume that all parts of the management system or process step are of equal importance resulting in resources for monitoring and control being spread evenly and, in an industry under tight financial constraints, too sparingly.

From a food safety perspective, probably the most telling point is that the food scares that have occurred in the past ten years have occurred despite the widespread adoption of ISO 9001 registration throughout much of the food chain. Reliance on end-product testing means that in many cases the food has already been consumed before the problem is identified.

Hazard Analysis and Critical Control Point

Hazard Analysis and Critical Control Point (HACCP) is a system of food safety assurance based on the prevention of food safety problems and is accepted by international authorities as the most effective means of controlling foodbourne diseases. HACCP is derived from "Failure Mode and Effect Analysis", an engineering system which looks at a product and all its components and manufacturing stages and asks what can go wrong with the total system. HACCP is a management tool that provides a more structured approach to the control of identified hazards than that achievable by traditional inspection and quality control. Rather than relying on the job being done correctly to avoid risks, it specifically asks the questions "What are the hazards," "What could go wrong with the system" and "What controls do we have to prevent the problem arising." A significant feature of HACCP is that it involves pro-active risk assessment. It still requires end-product testing but it is able to identify areas of concern where a process failure has yet to take place and implement the necessary monitoring and control procedures to hopefully prevent a problem arising. It is flexible and requires changes according to variations in the different stages of the production process and as such is very much company and process specific. Until recently, HACCP had been confined to the processing and further processing end of the food chain. It is appropriate that HACCP, having its origin in the food industry, be applied to the production of animal feed given the feed problems referred to earlier and the widespread acceptance of the importance of the animal feed within the "farm to fork" food chain. Food and Agriculture Consultancy Services (F.A.C.S.) was one of the first food consultancy businesses to promote the benefits of the application of HACCP throughout the food chain from farm to fork. Working in conjunction with the UK's leading supermarket, Tesco, F.A.C.S has pioneered the implementation of HACCP within the feed industry in UK and parts of Europe and Asia.

Within the feed operation there are many hazards or sources of contamination that are not specific to a particular process step, e.g. environmental hygiene. The control of these "day-to-day" potential hazards is normally part of GMP and as such are referred to as prerequisite programmes. The prerequisite programmes must be in place before HACCP can be completed and as such underpin the entire HACCP system. There are three key areas that are covered by GMP, namely, the premises, personnel and product. Typical examples are shown in Table 1. Effective prerequisite programmes enable the HACCP system to be focused on the significant product and process feed safety hazards that require specific control to assure consumer or animal safety and therefore reduce the number of critical control points that can be effectively managed.

Benefits of Implementing a HACCP system

The application of due diligence within the feed industry is now widely accepted. The implementation of a HACCP system will enable a complete process specification to be produced for a feed mill from raw material procurement to finished product delivery. Traditional methods of control rely on retrospective analysis where as HACCP places the control within the manufacturing environment such that quality is "built-in" not "tested-out". HACCP provides the means of minimizing or eliminating the risk of hazards occurring during the process. The same technique can potentially identify areas of concern where failure has not yet been experienced and in this context makes it particularly useful when considering plant modification or new feedmill designs. In addition, HACCP focuses on the importance of equipment maintenance and calibration and the observing and recording of process parameters.

HACCP is entirely compatible with existing quality systems such as ISO 9001:2000 and GMP. The HACCP system requires essential documentation that will already be utilized within the quality system, e.g. operating procedures, work instructions and calibration and testing techniques.

Table 1. Example Prerequisite requirements for HACCP

Area	GMP Requirements
Premises	good hygiene design of buildings and equipment preventative maintenance and calibration schedule written cleaning procedures pest control programme control of chemicals and additives
Personnel	documented personnel hygiene procedures, including rules for protective clothing, jewellery policy and hand washing
Product	effective supplier approval for feed ingredients and packaging storage procedures for feed ingredients and finished products transport hygiene procedures traceability and rapid recall system

Implementing HACCP within a Feedmill

The implementation of HACCP involves seven recognized steps (Table 2). It is essential that prior to implementing HACCP full management and financial commitment is secured. HACCP involves all employees from cleaning operatives to CEO's and it is not a concept that can be delegated to a particular section of the mill operation. Training should be organized for all employees such that they understand not only their own responsibilities within HACCP but also the total concept of the system combined with knowledge of food safety, contamination risks and hygiene.

Although there are a number of different versions of HACCP, the standard that is recognized internationally is that produced by Codex Alimentarius Commission, 2001. When conducting a HACCP study the seven principles may be applied in fourteen stages as shown in Appendix A (Campden & Chorleywood 2003).

Table 2. HACCP PRINCIPLES (Codex Alimentarius Commission 2001)

Step 1:	Conduct a hazard analysis
Step 2:	Determine the critical control points (ccps)
Step 3:	Establish critical limits
Step 4:	Establish a system to monitor control of the ccp
Step 5:	Establish the corrective actions to be taken when monitoring indicates that a particulaer ccp is not under control
Step 6:	Establish procedures for verification to confirm the Haccp is working effectively
Step 7:	Establish documentation concerning all procedures and records appropriate to these principles and their application

Stage 1. Define terms of reference / Scope of the study

The terms of reference need to state the specific product or process line on which the HACCP study is carried out and the precise start and end point. It is also necessary to define the biological, chemical and physical hazards that are to be considered. Hazards that are usually considered within the feedmill are indicated in Table 3.

Table 3: Example hazards in a feedmill

Hazard Type	Example
Physical	glass, metal, wood, faeces, insects, weed seeds
Chemical	pesticides, dioxins, mycotoxins, drug residues, chemical residues, PCB's, heavy metals
Biological	moulds, salmonella, enterobacteria

Stage 2. Select the HACCP team
The optimum number is between 3 – 6 people. Try where possible to include members of staff with a range of expertise, i.e. production, quality control, technical manager etc. Other individuals may be required for specific stages, e.g. purchasing department. At least one member of the team should attend a recognized HACCP training programme. Set a realistic timetable. Six months would be a typical timescale for setting up HACCP, implementing, monitoring and reviewing.

Stage 3. Describe The Product
A full description of the finished product or products under study should be prepared including processing, packaging, storage and shelf life.

Stage 4. Identify intended use
Define the species of animal the feed is designed for.

Stage 5. Construct a flow diagram
This is a line diagram showing each stage of the mill process. It should include each process step from raw material to dispatch and not forgetting recycle/rework loops. Sequential numbers assigned to each step enable easy reference to subsequent documentation.

Stage 6. On-Site Confirmation Of Flow Diagram
The HACCP team should undertake a physical check of the mill compared to the flow diagram to verify accuracy and completeness.

Stage 7. List all potential hazards associated with each process step, conduct a hazard analysis and consider any measures to control the identified hazards (Principle 1)
Using the flow diagram the HACCP team must list all the potential hazards defined in the terms of reference that may be present in the raw materials, hazards that may be introduced during the process and hazards that survive the process step (Table 4). The HACCP team should next conduct a risk assessment (Hazard Analysis) to determine which hazards are of such a nature that their elimination or reduction to acceptable levels is essential to the production of safe feed. The risk assessment will be based upon various considerations including frequency of the hazard occurring and severity of the hazard, e.g. life-threatening/mild, chronic/acute. The HACCP team must then consider what control measures, if any, exist which can be applied to each hazard. Control measures are those actions that prevent, eliminate or reduce hazards to an acceptable level. For example if the hazard were metal contamination in incoming raw materials, one control measure would be the operation of magnets within the feedmill.

Table 4. The Three Key Control Stages of Prevention within a Feedmill

Stages of Prevention	Application examples for Feedmills
Hazard Contamination	incoming raw materials and external elements, e.g. air and water
Hazard introduction or accumulation	cross contamination (introduction) and microbial proliferation (introduction and / or accumulation)
Hazard Re-contamination	coolers, bulk and bag loading, and delivery

Step 8. Identify the Critical Control Points (Principle 2)
CCPs are those steps in the process that are essential to prevent or eliminate food safety hazards or reduce them to an acceptable level. The identification of CCPs requires experienced judgement and common sense and may be aided by the use of a HACCP decision tree (Appendix B). There will be many control points throughout the feed mill but only a certain number will be defined as critical. It is also important to differentiate between critical control points for food safety and quality control points for feed quality. Hazards managed by the prerequisite programmes do not require the application of the decision tree because they must be maintained as specified. Certain control points may not

be critical because of a CCP later in the process, e.g. microbiological contamination early in the process may be considered as low risk because it is removed by a heating stage later in the process. In practice, many HACCP plans over-estimate the initial number of CCPs. The review process, however, provides a useful means of assessing whether a control point is critical or not.

Step 9. Establish Critical Limits for each CCP (Principle 3)

Each CCP must have a critical limit for the control measures which is the level that separates safe product from unsafe product. Some of these limits may be defined in legislation or customer requirements, e.g. mycotoxin levels or drug residues. Other limits will be based on validation exercises such as heat treatment time and temperature. In practice a target level may be specified with a pre-determined tolerance indicating the degree of latitude allowable. The critical limit must be measurable and preferably quick and easy and on-line, although certain tests in a feedmill may be retrospective. Many feed mill computer process controls automatically record parameters such as temperature and time for expanders and conditioners.

Step 10. Establish A Monitoring System For Each CCP (Principle 4)

This is an essential part of the HACCP study and defines the format by which the CCPs are monitored and recorded to demonstrate that the process is under control. Monitoring will be a planned sequence of observations or measurements. The following parameters must be considered:

- What test is to be performed
- How frequently it should be carried out
- What levels are acceptable
- Where the results are to be recorded
- Who is responsible for performing the test
- What to do if the result is outside of the limits

The monitoring results need to be reviewed and acted upon within the context of the Quality System. This will usually be on a daily basis to ensure all the CCPs are being adhered to. A weekly or monthly meeting may then pull together the results to investigate any CCP that is not being maintained within the critical limit. An example of monitoring procedures in a feedmill would be the visual inspection of incoming raw materials to verify the absence of physical contamination, the frequency being every load.

Step 11. Establish a Corrective Action Plan (Principle 5)

Arguably the most significant aspect of HACCP is the provision for the remedial actions that must be taken to bring a process step back within limits in the event of a critical limit being exceeded. These actions need to consider the past, present and future in terms of feed that has already been manufactured, feed currently being manufactured and feed that will be manufactured in the future to prevent a repeat of the problem. The HACCP system must describe who will do what and when and contingency must be established for what to do with non-conforming finished feed. All corrective actions must be recorded and reviewed in order to ensure that the hazard has successfully been returned within the critical limit.

Step 12. Verification including validation (Principle 6)

This stage comprises two distinct activities:

- Validation
- Verification

Validation

The contents of the HACCP plan must be validated prior to implementation. The objective of validation is to ensure that the hazards identified in the plan are complete and correct and to demonstrate that the selected hazard is effectively kept within the critical limits by the control measures. In most cases this will involve testing at the control points both prior to implementation and periodically afterwards. As an example, feedmills that flush the mixer after manufacturing feed containing a drug or additive,

must validate the process by testing the level of carry-over residues for the amount of flush material specified. Another example is validation of heat treatment equipment for the eradication of bacterial contamination in the feed.

Verification

The two main aspects of verification are to demonstrate conformance with stated procedures and collation of data to demonstrate that the HACCP system and prerequisites are effective. The verification procedures should involve internal and external audits which would seek to establish amongst other things, corrective action records, non-conforming product, customer complaints and management review records.

Step 13. Review the HACCP system

The developed HACCP system should initially be run for at least three months and then reviewed by both the HACCP team as well as the plant operatives running the system. At this stage it is likely that the number of CCPs may be reviewed. Any amendments should be fully documented. After the initial three month review it is recommended that the HACCP system is formally reviewed at least twice a year and more frequently if the product risk is high. The HACCP system should be subject to continual improvement and modification. At any point at which modifications are made to the plant the mill flow diagram needs to be amended and a further review should be carried out to assess the potential impact in terms of CCPs.

Stage 14. Establish documentation and record keeping (Principle 7)

Effective and accurate record keeping systems must be defined so that safe production of feed and corrective actions to correct deviations from critical limits can be demonstrated. It is suggested that a monthly record for each CCP is maintained in a format that can clearly demonstrate the systematic control and or reduction of each hazard

A Working HACCP Plan

Unfortunately in some companies, the certificate associated with a quality system is more important than the system itself. Too often, documentation is left on the shelf gathering dust awaiting the next scheduled audit. HACCP and GMP cannot operate successfully filed away in an office. The activities associated with GMP and HACCP must become part of the daily management function of the mill. A successful HACCP plan not only assures feed safety it results in improved efficiency of production and improved feed quality and performance.

Conclusion

Animal feed is an integral part of the human food chain and many of the global human food safety scares have been directly related to the feed consumed by the animal. More importantly, many of the incidents could have been prevented if the appropriate risk assessment and controls had been in place within the feed industry. The implementation of a HACCP system should be viewed as a necessary step in the process of due diligence to satisfy the increasing concerns about food safety from both retailers and consumers. HACCP implementation is a fulfilling exercise because it is proactive, the objectives can clearly be demonstrated and it involves all employees not just a team of QA staff. Finally, HACCP is totally compatible with existing Quality Systems, therefore the majority of the documentation required already exists.

APPENDIX A

Stages in a HACCP Study (Campden & Chorleywood 2003)

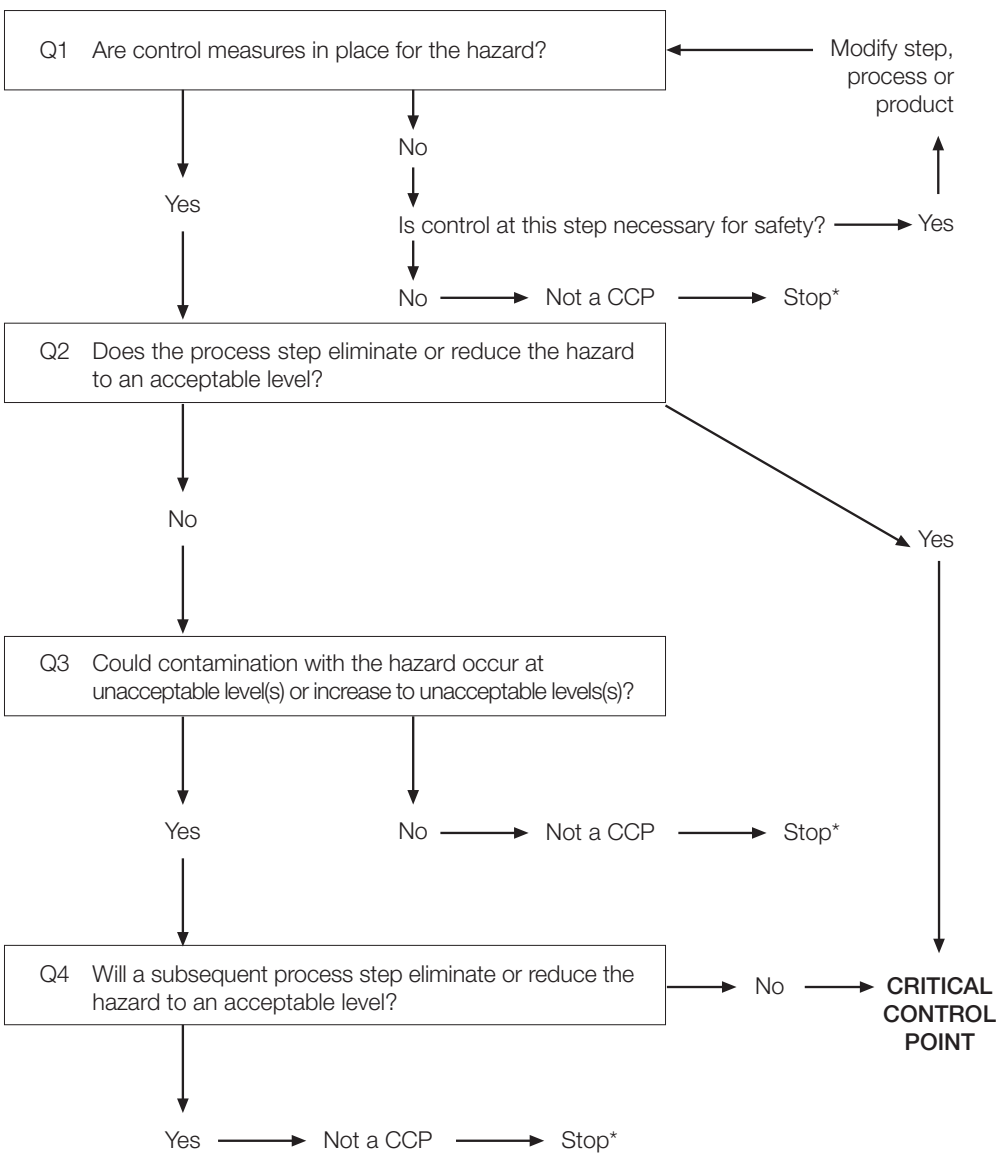
Stage 1	Define terms of reference / scope of the study
Stage 2	Select the HACCP team
Stage 3	Describe the product
Stage 4	Identify the use
Stage 5	Construct a flow diagram
Stage 6	On-site confirmation of flow diagram

Stage 7	List all potential hazards associated with each process step, conduct a hazard analysis and consider any measures to control identified hazards
Stage 8	Determine CCPs
Stage 9	Establish critical limits for each CCP
Stage 10	Establish a monitoring system for each CCP
Stage 11	Establish a corrective action pla
Stage 12	Verification including validation
Stage 13	Review the HACCP
Stage 14	Establish documentation and record keeping

Appendix B

Ccp Decision Tree

Answer each question in sequence at each process step for each identified hazard



** Proceed to next step in the process*

Potassium Diformate: An Exciting New Alternative To Antibiotic Growth Promoters

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Introduction

Antibiotic growth promoters have been widely used in animal nutrition, with considerable success. However, following their long-term use, there are concerns about the development of resistance of bacteria to certain antibiotics. This has serious implications for both human and animal health. Consumers see the use of antibiotic growth promoters with concern and are wary about the indiscriminate use of antibiotics. Politicians and consumers have been discussing the issue in a non-scientific way over the last few years. Concern over the health risks associated with the use of antibiotics as feed additives has led the European Community to ban a number of in-feed antibiotic growth promoters in the late 1990s. In 1997, avoparcin has been banned followed by the ban of four commonly used products virginiamycin, spiramycin, zinc bacitracin and tylosin. The European Community has imposed a complete ban of all in-feed antibiotic growth promoters from 2006 onwards.

According to a report published by the WHO in 1997 there is no doubt that there is an increase in the level of resistance in bacteria against commonly used antibiotics in human medicine. However, it is difficult to say whether the resistance is a characteristic of the bacteria or whether it has been driven by the use of in-feed antibiotic growth promoters.

The removal of in-feed antibiotic growth promoters as decided by the European Community has consequences for animal health and performance and has prompted the interest in alternatives, which can assure efficiency in the animal and safety to the consumer. However, alternatives to antibiotic growth promoters must fulfill certain prerequisites to be generally accepted by the feed industry.

1. An acceptable alternative to antibiotic growth promoters must have a significant beneficial impact on animal performance and animal health. This improvement can be reflected in higher weight gains, improved feed conversion ratio or reduced incidence of diseases. The performance effects of antibiotic growth promoters have been evaluated in several reports in the 90th. Based on a total for 1200 experiments with pigs average growth increased by 16% in nursery pigs (7 to 25 days) and by 4% in growing finishing pigs (24 to 89 days). At the same time feed conversion ratio improved by 7% and 2% respectively. Even though these are relatively old data and the genetic potential and management of pigs has changed dramatically, alternatives to antibiotic growth promoters have to compete with these performance improvements.

2. At least as important as the performance effects is the safety of alternatives both to the animal and the human population. A minimum requirement for alternatives to antibiotic growth promoters is to obtain a GRAS (generally recognized as safe) status. Some countries even require specific tolerance and toxicity studies in order to make sure that a new feed additive is safe.

3. For the user of new feed additives the handling properties of a product are of particular importance. Alternatives to antibiotic growth promoters must be easy to handle and easy to apply. The new product must allow homogenous distribution in the feed with sufficient stability during the feed manufacturing process. Ideally the product should withstand the temperatures during the conditioning and pelleting process and guarantee sufficiently long shelf life.

4. Last but not least alternatives must be cost effective and supply enough return on the investment. For the economical evaluation of potential alternatives to antibiotic growth promoters not only the traditionally used parameters feed cost and cost of the additive but also the final product price has to be taken into consideration. The use of alternative non-antibiotic growth promoters may create a unique market and allow the product to enter more profitable market segments.

Potassium Diformate: A Registered Non-Antibiotic Growth Promoter

The European Community has registered potassium diformate as the first and only non- antibiotic growth promoter for use in pig feeds under EC No. 1334/2001. The registration process for the product in Asian countries is under way and approval in most of the countries is expected by third quarter this year. This provides a new opportunity for pig producers to remove antibiotic growth promoters from their feeding programs.

The nutritive application of formic acid and formates has been demonstrated to be an effective tool to improve performance of growing pigs. In the gastro intestinal tract organic acids inhibit undesirable microorganisms like *E. coli* or *Salmonella*, hence reduce the proliferation and colonization of potentially pathogenic bacteria. As a result the incidence of diarrhea is reduced.

Performance Effects Of Potassium Diformate

Comprehensive studies have shown that the performance of growing pigs can be improved significantly by the use of organic acids. As a consequence industrial feed additives have been developed containing only one or combinations of organic acids or their salts. One of the latest developments is the development of potassium diformate. Potassium diformate contains 35.4% of Formic acid, 34.6% Formate and 30% Potassium.

A dose titration trial has been conducted at the Technical University of Munich/Germany Paulicks et al., 1996) to evaluate the effect of increasing inclusion levels of potassium diformate on performance of growing piglets. Potassium diformate was added at 0%, 0.4%, 0.8%, 1.2%, 1.6%, 2.0%, 2.4% and 2.8% to a piglet starter based on corn, wheat and soybean meal. A total of 48 piglets were kept in individual cages and fed the experimental diets for 42 days. The experiment started at an average live weight of 7.4 kg for all treatments. Feed and water were available ad libitum. The performance data weight and feed conversion ratio are shown in Figure 1 and 2 below. The supplementation with potassium diformate improved daily weight by 13%, daily feed intake by 9% and feed conversion ration by 4% on average over all supplemented groups. There was a clear dose effect of potassium diformate on weight gain reaching a maximum of 590 g/day with an inclusion rate of 2% potassium diformate. This was a significant improvement of 22% compared to the untreated control group (483 g/day). Feed intake was improved by the addition of potassium diformate reaching a magnitude with an inclusion rate of 2%. Feed consumption in this treatment was 880g/day, which was 15% higher than in the untreated control treatments (770 g/day). Higher application rates of potassium diformate tended to decrease feed intake. Feed conversion rate improved linearly from 1.59 kg consumed feed per kg live weight gain in the control group up to 1.47 kg consumed feed per kg weight gain in the treatment containing 2.4% potassium diformate, which is an improvement of 8%.

Figure 1: Effect of incremental level of potassium diformate on weight gain of growing piglets

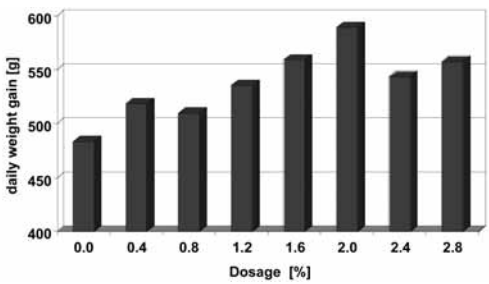
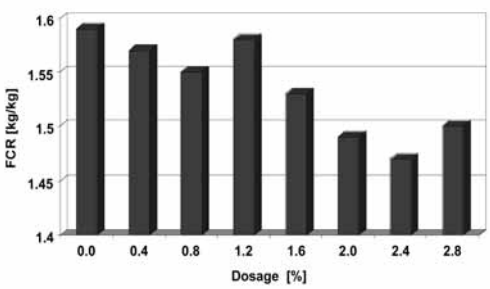


Figure 2: Effect of incremental level of potassium diformate on feed conversion ratio of growing piglets



Besides the experiment described above, more trials have been conducted with growing piglets to evaluate the performance effects of potassium diformate depending on the supplementation rate to feed. A summary of five different trials is shown in Figure 3 and 4 with respect to effects on weight

gain and feed conversion ratio. Regression analysis has been used to predict performance improvements depending of the dosage of potassium diformate in the feed. Based on the five trials used for the evaluation of the effects of increasing level of potassium diformate it can be concluded that weight gain improves by about 8% per percent of potassium diformate inclusion. With a maximum inclusion level of 1.8% as registered by the European authorities weight gain can be improved by up to 14%.

Feed conversion ratio increased linearly up to the maximum dosage of 2.5% potassium diformate. The maximum registered dosage of potassium diformate in piglet feed is 1.8%. Using the regression equation based on five different trials the improvement in feed conversion achievable by 1.8% of potassium diformate is 8.1%.

Figure 3: Effect of increasing supplementation of potassium diformate on weight gain of piglets (summary of five trials)

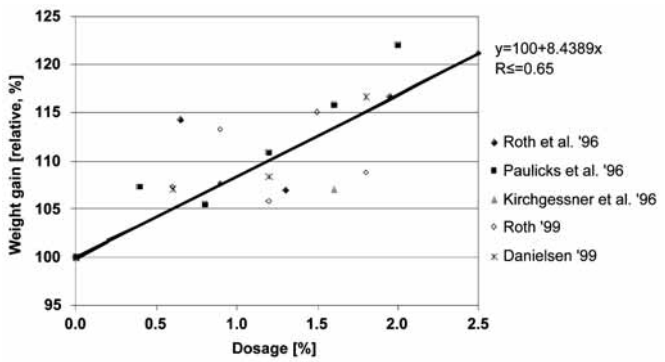
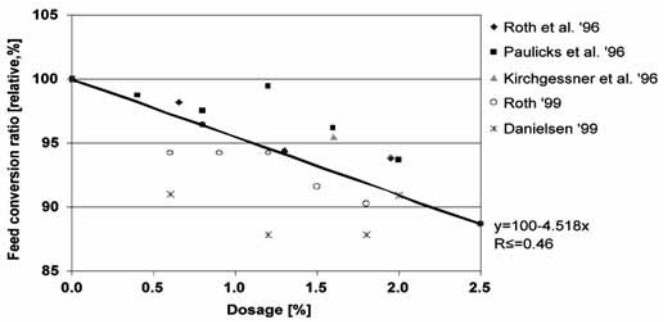
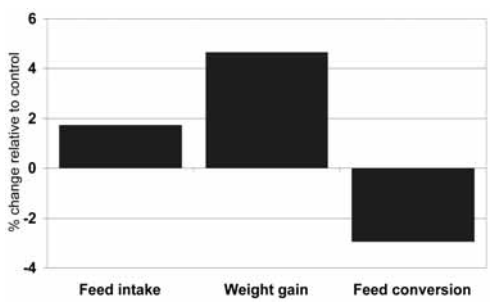


Figure 4: Effect of increasing supplementation of potassium diformate on feed conversion rate of piglets (summary of five trials)



Microbial infections and digestive disorders with resultant reduction of performance are not limited to the young piglet only. Growing and finishing pigs can experience problems especially in phases of environmental changes and stress. In order to prevent digestive problems and improve performance, prophylactic supplementation with antibiotic growth promoters is common practice for weaner and grower diets. A number of trials have been conducted to determine the effects of potassium diformate in the grower and finisher phase. The summary of six studies with an average supplementation rate of 0.9% of potassium diformate is shown in Figure 5.

Figure 5: Influence of potassium diformate (0.9%) on performance of growing/finishing pigs

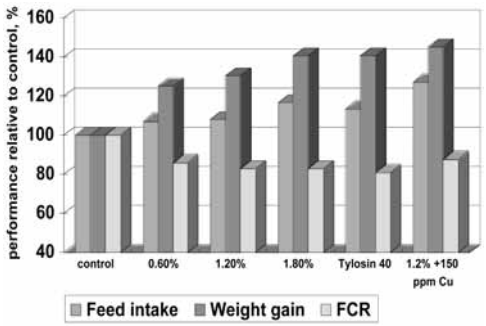


The application of 0.9% of potassium diformate to grower/finisher diets improved feed intake on average over six trials by about 2%. Weight gain increased by more than 4 % and feed conversion ratio was improved by about 3%. These data indicate that the addition of potassium diformate is not only beneficial in growing piglets but also in growing and finishing pigs.

Potassium diformate is registered as a non-antibiotic growth promoter with the purpose to replace in feed antibiotics ensuring safer products to the consumers. Therefore the benefits of using potassium diformate have to be compared to effects achieved with the conventional use of in feed antibiotics. One of the commonly used feed antibiotics in pigs is Tylosin. A trial has been conducted in Denmark (Danielsen, 1998) comparing performance of pigs either treated with the antibiotic growth promoter Tylosin or with potassium

diformate. A total of 120 piglets were assigned to 6 different treatments. All piglets were individually housed for a period of four weeks and had free access to feed and water. The experiment involved on untreated control group, three treatments with increasing levels of potassium diformate (0.6%, 1.2% and 1.8%), one treatment with a supplementation of 40 ppm Tylosin and one treatment with a combination of 1.2% of potassium diformate and 150 ppm Cu. The results of the trial are summarized in Figure 6. Weight gain increased by 40% with the application of 1.8% potassium diformate, 40 ppm Tylosin and the combination of 1.2% potassium diformate and 150 ppm Cu. Feed conversion ratio improved by about 20% in the groups fed on 1.8% potassium diformate and 40 ppm of Tylosin. The results of this trial clearly demonstrate that potassium diformate can replace a feed antibiotic without a negative impact on animal performance.

Figure 6. Effect of potassium diformate and Tylosin phosphate on performance of piglets between 9 and 21 kg of live weight

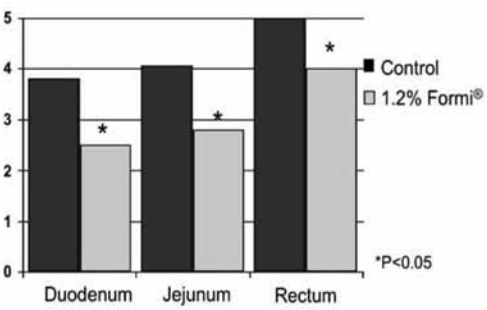


It has been demonstrated in a number of trials that potassium diformate significantly improves animal performance to an extent comparable to commonly used feed antibiotics. The performance effects of potassium diformate are mainly a result of its anti-microbial properties. With respect to the mode of action of potassium diformate there are three major aspects.

The Reduction of the Microbial Load

Although organic acids generally lower the pH value in the stomach and parts of the upper gastro intestinal tract and therefore enhance proteolytic activities, a major effect of potassium diformate lies in the alteration of the microbial flora within the gut. Trials have shown that potassium diformate is significantly reducing the total number of coliform bacteria in then duodenum, jejunum and rectum. Figure 7 shows the results of a trial where pigs were fed either a control diet or a diet supplemented with 0.6 % or 1.2% of potassium diformate (Overland et al. 1999). A total of 95 pigs were assigned to one of the three treatments. Average initial weight was 27kg and average final weight was 104 kg. Pelleted feed and water were available ad libitum. A microbiological examination was conducted on digesta collected from eight pigs each from the control and the 1.2% potassium diformate group. From each pig, samples were taken from three locations in the intestinal tract: the middle of the duodenum, the jejunum and the rectum. Adding 1.2% of potassium diformate to the feed decreased the total number of coliform bacteria significantly by 1 to 2 logarithmic units in all segments of the intestinal tract. The focus in this study was on coliform bacteria, which belong to the group of enterobacteria. *E. coli* is by far the dominant type among coliform bacteria in the gastro intestinal tract but the effect of potassium diformate on coliform bacteria can be assumed to be representative for most enteric bacteria such as *Salmonella* or *Enterobacter*.

Figure 7: The influence of potassium diformate on total coliform bacteria in the intestinal tract of finishing pigs



The Ph Lowering Effect

The performance enhancing effects of organic acids and their salts are extensively described in the literature. As reasons for these effects, the influence of organic acids on the feed itself (bacterial contamination), on the intestinal area and on the intermediate metabolism are discussed but mainly the 2 latter aspects seem to be more relevant. As piglets immediately after weaning have an inadequate HCl production in the stomach, the addition of organic acids helps to support the physiological

digestive functions by decreasing the pH value in the stomach. This effect of lowering the pH value in the stomach is of high importance especially in feed having a high buffer capacity. Potassium diformate contains as active ingredient free formic acid as well as formate.

The strong anti-microbial effect of potassium diformate can be explained by the high concentration of active ingredient present not only in stomach but also in the duodenum. A kinetic study with pigs has shown that 85% of the formates in potassium diformate pass trough the stomach and results in a pH reduction of 0.4 units in the duodenum. Figure 8 shows the retention of formates in different parts of the gastro intestinal tract.

Figure 8: Retention of formic acid and formate in different parts of the gastro intestinal tract

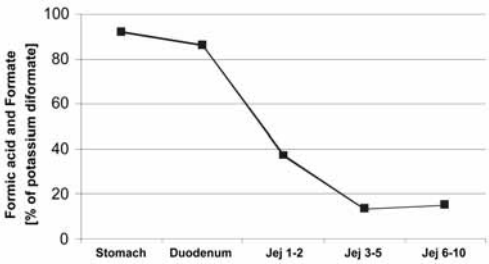
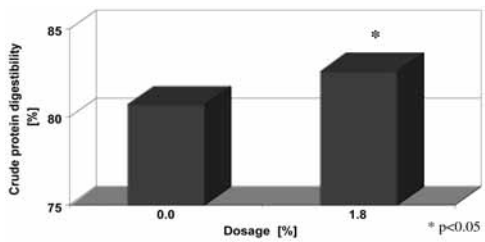


Figure 9: Effect of potassium diformate on the digestibility of crude protein



Effect on Nutrient Utilization

Performance effects of organic acids are not only related to their effects on unfavorable microorganisms and the property to lower the pH value in the gastro intestinal tract. Furthermore, the anion of the acid has a positive influence on the eubiosis among the intestinal micro-flora. All these effects relieve the intermediate metabolism and contribute to a higher performance. An improved nutrient utilization is partly a result of a decreased competition from microorganisms for nutrients but is also a result of a more efficient enzymatic digestion of nutrients. A metabolic trial (Roth et al. 1998) has been conducted involving a control group and a treatment supplemented with 1.8% of potassium diformate. Piglets used for this experiment had an average live weight of 9 to 12 kg. Excreta were collected twice daily and digestibility was determined for dry matter, crude protein, crude fiber, crude fat N-free extracts and gross energy. The results of the trial show that the application of 1.8% potassium diformate increased digestibility of dry matter, crude protein, N-free extracts and gross energy significantly. The improvements in digestibility reflect primarily changes in the activity of the hindgut micro-flora. Since about 80% of the fecal nitrogen is of microbial origin the results obtained in this study indicate that the supplementation with potassium diformate reduced the amounts of fermentable nutrients entering the hindgut by improving the enzymatic digestion in the small intestine. Figure 9 shows the results of the digestibility study.

Handling Properties of Potassium Diformate

Potassium diformate is a white, dry, crystalline powder without the typical formic acid odor. The product has a low corrosiveness to feed mill equipment and to persons handling the product. Evaporation losses during the feed production process are extremely low. One of the most critical steps for feed additives in the whole chain of feed production is the conditioning and pelleting process with relatively high temperature being involved. The retention of potassium diformate after conditioning/expanding pig feed at around 100°C has been measured in several tests. The results show that retention of formic acid and formate after this harsh production process was above 98%. These data indicate that even an expansion process frequently used for piglet feed does not have a negative impact on potassium diformate. The formulation is absolutely stable during feed production processes. Besides the stability during the feed production process, the shelf life of the product either as a straight product or mixed into feed is of importance. Extensive tests have shown that potassium diformate is extremely stable even at high ambient temperature of up to 40°C. The results of these tests recorded losses of only about 0.5% during a storage period of 12 month. Mixed into premixes potassium diformate has no negative impact on the stability of vitamins or other feed additives like amino acids. Potassium diformate is either supplied to the feed via a premix or added to the feed directly. The mixing homogeneity of this new product has been tested both with a premix and a

finished feed. In both cases an excellent mixing homogeneity could be achieved expressed by coefficients of variation in the rage between 3 and 4 %. Therefore it can be concluded that segregation during transportation and unloading is not a problem with potassium diformate.

Conclusion

Extensive research activities have proven that potassium diformate improves animal performance in terms of weight gain, feed intake and feed conversion. The improvements in performance are equal to the results obtained with antibiotic growth promoters. Therefore potassium diformate with its performance and health enhancing properties is an effective alternative to feed antibiotics. Potassium diformate improves performance equal to antibiotic growth promoters without the risk of developing resistance in microorganisms.

Potassium diformate is a dry odorless powder with a low corrosiveness to equipment and the user. It is easy to handle and absolutely safe for the user and the consumer or animal products. Potassium diformate reduces the incidence of *E. coli* and *Salmonella* in retail meat products and therefore contributes substantially to food safety.

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Pathogen Control In Feedmills

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Introduction

Feed has long been recognised as one of the most effective vectors for spreading bacterial contamination to a large number of animals. The unprecedented rise of foodborne salmonellosis in Western Europe during the 1980s and 1990s resulted in many new control measures, firstly in the feed and poultry industry and later in the pig and beef industries. Quality feed is one of the ingredients of management that can help maintain the healthy status of all livestock. Implementing an effective pathogen control programme is an essential prerequisite for quality feed. To reduce the pathogen levels in animal feed we need to consider the three stages of prevention (Table 1). An integrated approach is required to implement a HACCP plan (hazard analysis and critical control point) at the different stages of the process, including incoming raw materials, feed manufacturing and transportation.

Table 1. The Three Key Control Stages of Pathogen Prevention within a Feedmill

Stages of Prevention	Critical Control Points
Pathogen Contamination	control of incoming raw materials and external elements, e.g. air and water
Pathogen introduction or accumulation	kill organisms within the feed and prevent microbial proliferation within the mill
Pathogen Re-contamination	hygiene of coolers, loading, and delivery

Raw Material Selection and Purchase

Good quality feed is about careful selection of raw materials, not just nutritional values and requirements. Raw materials need to be carefully sourced, managed and stored to avoid the risk of introducing excessive bacterial contamination. Most raw materials are grown, harvested, processed and transported by someone outside the feed industry. These ingredients are often handled up to 10-15 times before reaching the feedmill, where they can be stored for later use. The handling of the raw materials can increase the frequency of broken or damaged particles or grains which will increase the risk of microbial and mould contamination. The feed ingredient quality control component of a feed operation is therefore an important first step in preventing the contamination of animals on the farm.

When purchasing raw materials the primary consideration is to only purchase from approved suppliers. In countries where there is no recognised raw material supplier code of practice, the approval of suppliers is based on supplier history; suppliers that frequently supply out of specification, poor quality ingredients are removed from the approved suppliers list. The approval of suppliers can be backed up by questionnaires detailing the quality management systems and Good Manufacturing Practices (GMP) for the processing, storage and transport of raw materials. High risk raw materials or suppliers should also be audited by the purchasing company to confirm compliance with the stated quality system. The transport of raw materials is a very important consideration, because failure to clean the vehicles adequately can lead to contamination of the next load of material to the feedmill. It is a standard procedure in many countries to require hauliers to state the last three loads prior to delivery of the purchased raw materials as well as the cleaning procedures. It is also necessary to ensure hauliers never transport materials harmful to animals or humans in the same vehicle as feed ingredients, e.g. litter, offal and carcasses.

Contamination

Feed ingredients can be contaminated by a large number of potentially pathogenic micro-organisms. Many of the bacteria that contaminate raw materials and feed are found in the gut of animals and

humans. Contamination of raw materials therefore is most often a result of poor hygiene and faecal contamination from rodents, insects, birds or humans. The pathogen most frequently associated with animal feed is salmonella and the subsequent contamination of eggs and meat in poultry. The poultry industry around the world has risen to the challenge of salmonella contamination in feed and much work has been done investigating contamination rates in raw materials and finished feed. During the 1980s and 1990s, the unprecedented rise in salmonellosis in the UK, spurred the feed industry into closer examination of control measures designed to reduce the incidence of salmonella in feed. In the UK, monitoring of feed ingredients for salmonella is compulsory and the data in Table 2 supplied by the Department of Environment, Food and Rural Affairs (DEFRA) for the year 2001 shows that salmonella still features as a hazard to the feed industry. Whilst processed animal proteins and protein by-products have long been associated with an increased risk of microbiological hazards, oilseed products can also be contaminated at a similar rate if the bacteria are present either during or after processing. Although the serotypes isolated in raw materials and feeds are frequently not those most commonly found in animals or humans, vegetable protein sources have been shown to contain pathogenic salmonella serotypes. Table 3 shows the trend for the number of positive *S enteriditis* and *S typhimurium* from all feedstuffs and raw materials monitored by DEFRA during the 12 month period. The advent of vegetable only animal feeds does not therefore necessarily reduce the risk of salmonella contamination in finished feed. Apart from salmonella, other pathogens that would be considered within the feedmill HACCP plan would include *E coli, Clostridia, Staphylococcus, Streptococcus* and *moulds*.

Table 2. Incidence of Salmonella across a range of animal feedstuffs and raw materials, tested by DEFRA, during January – December 2001

Product	Number of tests	No of positive tests	Percent positive
Processed animal protein at a GB protein Processing premises	5,866	128	2.2
GB and imported processed animal protein Arriving for feedingstuffs use	1,350	33	2.4
GB crushing premises – oil extracted seed meals (rape, sunflower, linseed, soya, palm)	14,482	323	2.2
Non-oilseed meal vegetable proteins	14, 370	227	1.6
Pig and poultry meals	5,274	58	1.1
Poultry extrusions	6,320	27	0.43
Pig extrusions	2,124	8	0.38
Ruminant concentrates	2,655	24	0.9
Protein concentrates	805	12	1.49
Minerals / others	1,837	18	0.98

Table 3. Isolations of S enteriditis and S typhimurium from all feedingstuffs and feed ingredients monitored by DEFRA

Type of material	1994		1995		1996		1997		1998		1999		2000		2001	
	Se	St	Se	St	Se	St	Se	St	Se	St	Se	St	Se	St	Se	St
Finished feeds	4	25	2	20	0	18	2	7	0	8	0	7	0	9	2	4
Animal Protein	0	4	0	1	0	10	0	2	0	0	0	1	0	2	1	0
Vegetable Material	1	6	4	10	5	6	0	9	0	9	1	9	1	3	0	3
Minerals	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Miscellaneous	0	4	1	5	1	2	1	6	2	3	1	1	1	3	0	2
TOTALS	5	39	7	36	6	36	3	24	2	20	2	18	2	17	3	9

Although the poultry industry has been the focus of attention for salmonella control, the pig industry should be equally concerned. Other than the importance from a food safety and marketing perspective, salmonella plays an important role in animal health status. Increased mortality, lower daily gain, poorer feed conversion and higher medication costs are the net result. Table 4 shows an estimated cost of salmonellosis related to contaminated feeding stuffs from a study in Denmark.

The introduction of salmonella and other harmful pathogens into a feedmill cannot be prevented because microbial screening is impractical, expensive and time-consuming. Ingredients should always be inspected on arrival at the feedmill and rejected if they are contaminated with insects or rodent and bird faeces. Even if a load tests negative, the load could be contaminated due to the uneven distribution of the pathogens within the feed material. It is sensible therefore to assume that all raw materials may be potentially contaminated. It is also a feature that raw materials share intake pits at the feedmill and therefore the risk of cross contamination is high.

Table 4. Estimated costs associated with a salmonella outbreak (Neumann and Kniffen, 1999)

Parameter	Effect	Cost in affected groups (euros / head)
Average daily gain	Reduced by 45 g	0.54
Antibiotic therapy	Mass + individual treatment	0.27
Substandard pigs	Increased by 2%	0.90
Mortality	Increased by 3%	Up to 1.10
Quarantine and biosecurity costs	Various	0.23
Total cost per head at affected sites (depending on mortality)		1.94 – 3.04

Storage

Once arrived at the feedmill the handling and storage of raw materials is very important to prevent accumulation of pathogens. Rodents and birds must not be allowed access to the feedmill facilities including storage warehouses for ingredients and finished products. Wild bird, rodent and insect control programmes must be a prerequisite of HACCP. Silos must be cleaned on a regular basis, but care should be taken to avoid using water inside the silo. Moisture is a precurser for pathogen and mould growth and therefore dry cleaning techniques and fumigation should be considered. Dust control is equally important, particularly if intake pits are located close to the finished product loading area. The installation of dust extraction units is a common feature these days. The intake pits must be kept clean throughout the day and covers placed over them when not in use to deter rodents and birds.

Decontamination of Raw Materials and Feed

As indicated earlier, no matter how much care is taken in the sourcing and handling, all raw materials must be considered as potentially contaminated with pathogens. To produce feeds that are free of pathogens processes need to be applied that can eliminate salmonella and other bacteria. In feedmills these processes consist of heat treatment, chemical treatment or a combination of both. Monitoring salmonella within a feedmill is not easy because salmonella can be difficult to isolate and quantify due to the uneven distribution within the raw material, finished feed or mill environment. In the past few years, enterobacteriaceae testing has become an established procedure in many mills in Europe and increasingly in S E Asia. Salmonella are just one type of gram negative bacteria that belong to a larger family called the enterobacteriaceae, which includes *Escherichia coli*. Unlike salmonella, counting enterobacteriacaea is relatively easy to quantify and provides a very effective and quantifiable measurement of the hygiene status of raw materials, finished feed and the mill environment. Raw materials would have typical enterobacteriaceae levels ranging from 10 x 1 per gram of material to 10 x 6 per gram. High counts of enterobacteriaceae (in excess of 10 x 3 per gram) indicate high levels of gram negative contamination and the likely presence of salmonella.

Heat Treatment

Heat treatment processes are based on the heat sensitivity of bacteria and involve not only increased temperature but also adequate moisture and time to achieve the required reduction in bacteria. Pelleting feed will result in a reduction in bacteria but at standard temperatures (65-70 degrees centigrade) total decontamination is not possible and the residual bacteria can lead to subsequent multiplication. In Europe, a number of supermarkets specify the need for heat treatment for certain classes of poultry. In the 1980s expansion, “high temperature-short time” (HTST) conditioning and “super conditioning” became increasingly common in feedmills, not because of the pasteurisation characteristics but because of the ability to add higher levels of liquid addition and by-products addition. The history of feed related food safety scares in Europe has helped the development of reliable, more economical and traceable feed sterilisation. There are now a number of systems available, ranging from expanders and extruders to long-term conditioners and sterilisation chambers.

The type of equipment depends upon whether the requirement is for pelleted feeds or mash as well as consideration of plant layout and existing press and crumb facilities. It also depends on whether the aim is to achieve a total kill or knockdown (reducing the number of bacteria in the feed). There is no doubt that heat treatment is effective in reducing bacteria, provided the required conditions are met. In the UK, certain supermarkets specify a minimum of 82 degrees centigrade for two minutes at 15% moisture or a similar validated process. In addition, there must be the ability to retain or divert feed that does not reach the desired temperature. Validation is an important part of the HACCP process, whereby the specified critical limit(s) is shown to achieve a minimum 6 log reduction in salmonella or enterobaceriaceae levels of less than 10 cfu's (colony forming units) per gram.

Heat treatment requires high investment costs plus running costs of up to US$4.5 per tonne to produce the desired moisture and temperature. Another consideration is the effect of excessive heat treatment which can lead to solubilisation of fibres, denaturation of proteins and destruction of vitamins, enzymes and other heat sensitive components, e.g. probiotics. A personal investigation has identified reductions in vitamins post heat treatment of up to 20 percent. It is advisable to adjust premix vitamin levels to take account of the associated losses during heat treatment.

Re-contamination

One of the major considerations when applying heat treatment is ensuring that the treated feed does not become re-contaminated. To achieve this objective it is imperative that treated feeds do not share the same routes as non-heat treated feeds. It follows therefore that the heat treated line will require separate enclosed conveyors and elevators, coolers, fat coaters and finished product bins. The process of moisture addition for successful heat treatment can provide an excellent environment for bacteria to multiply downstream from the heat process. Coolers are a critical control point in terms of re-contamination. Not only are they operating at temperatures and moisture levels ideal for growth of salmonellae and other bacteria (condensation is often a problem) but they also draw in large volumes of air from within the mill which will be contaminated with dust. Salmonella can be carried through a mill environment on particles of dust from the raw material end of the feedmill to the finished product end. The cooler therefore can become a frequent and effective source of re-contamination. It is now recommended that feedmills that have installed heat treatment equipment in filter the air supply to the coolers, through a 5 micron or less filter. This can be achieved by either fitting filters to the air inlet to the cooler, or isolating the coolers in a separate room, and ducting the air from outside the mill through a filter into the cooler room. The HACCP study will identify the need to regularly inspect and clean the coolers as well as replace the filters. Other contamination points will include intake pits, bottom of bucket elevators and conveyors, mixers and top of finished product bins. Transportation must also be considered because dirty trucks will contaminate the sterilised feed. If volumes justify, it is desirable to have dedicated trucks that do not carry raw materials or non-heat treated feed for the transport of heat treated products. As well as testing raw materials and finished products, HACCP swab procedures are now a feature of many feedmills as a means of monitoring hygiene status of equipment, trucks and environment. Monthly swab samples are taken at strategic points to assess the microbial load before and after heat treatment or pelleting. On heat treatment lines the critical limit for surface swabs is as low as 10 cfu per square centimetre. The EU is currently considering implementing bacterial standards for feedmills.

Chemical Treatment

When tracking enterobacteriaceae results down-stream from the thermal process, there is often a subsequent increase in the number of bacteria for the reason outlined above. As a result it is possible for heat treated feed to contain high levels of enterobacteria at the point of loading onto the truck or into bags. To combat this threat, many companies utilise organic acids either as a replacement or in combination with heat treatment to prevent re-contamination.

Several commercial products in either powder or liquid form are available that are commonly based on propionic, formic acid and their salts. The antimicrobial properties are based on two effects. Firstly, there is a lowering of feed pH and secondly, the undissociated form can freely diffuse through the microorganism's membrane. Once inside the cell, the acid dissociates and suppresses cell enzymes and nutrient transport systems. Gram negative bacteria are more sensitive to acids than gram positive

bacteria. Less chemical is required to prevent recontamination in a heat treated feed than to reduce bacterial numbers in raw materials or unprocessed feed. Enhanced organic acid products are also available commercially. These contain aldehydes, turpines and surfactant in addition to the organic acids. The combination of these ingredients has a synergistic effect upon the bacteriocidal activity of the product. The enhanced products are sometimes not favoured because they are highly volatile and aldehyde fumes can be a problem if ventilation within the mill is not effective. On the plus side, the enhanced acids can generally be used at lower levels compared with acid mixtures. Low addition of straight acid salt mixtures are not recommended because reduction in bacterial numbers is limited and some mixtures at low levels can actually be used as an energy source by the microbes.

Strategically, organic acids can be used to reduce microbial contamination in raw materials as well as prevent the development of moulds which in turn hopefully reduces the risk of mycotoxin contamination. Many feedmills flush the intake pits and mixer as a routine to prevent the proliferation of bacteria within the mill process. In the absence of a heat treatment facility, organic acids can be used to kill bacteria in the feed and prevent re-contamination. An ideal system would incorporate both heat treatment for sterilisation and organic acid addition to prevent re-contamination.

Conclusion

Animal feed is a critical link in the farm to fork food chain. The chain is only as strong as the weakest link and only too frequently the feed industry has proved to be the weakest link. The control of pathogens in the feedmill is important because of the implications for food safety, the effects on international trade and the negative effects on animal performance. A strategic approach based on HACCP is the most effective means of risk assessment and control. In conjunction with GMP, control measures need to include sourcing and handling of raw materials, heat treatment and/or organic acid treatment. Finally, testing for enterobacteriaceae is a highly effective method of measuring the effectiveness of the control measures and assessing the hygiene status of raw materials finished products and the mill environment.

Prevention And Control Of Feed Industry Mycotoxins

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It is very difficult to define safe mycotoxin levels because even small levels can have a detrimental effect on immune system and metabolism. The other challenge is that mycotoxins are not visible and require specific equipment to be detected. Different measures can be taken to counteract mycotoxin related problems on the farm, the first of which is prevention in the field.

Prevention in The Field and During Storage

Prevention of fungal infections during plant growth, harvest and storage is the most rational and efficient way to avoid mycotoxin contaminations on agricultural commodities and subsequently all their negative impacts. Common practical measures are described in Table 1.

Table 1. Main preventive measures to prevent mycotoxin contamination

Period	Measures
Pre-harvest	Correct management of previous crop residues
	Crop rotation
	Selection of good quality seeds
	Reduction of plant density
	Balanced fertilization
	Preventive and accurate insect and fungal management
Harvest	Appropriate harvesting time
	Appropriate harvesting equipments and procedures to minimize crop damage
	Removal of damaged and humid portions of crops
Storage	Storing without delay in good storage facilities under moisture-, temperature-, humidity- and insect-control
	Adding antifungal agents of low toxicity (such as propionic acid) or chemical preservatives (e.g. acid type inhibitors such as benzoic, sorbic, acetic, propionic acids and salts)

However, contamination of agricultural products with fungi that are able to produce mycotoxins is often unavoidable and of worldwide concern. The economic impacts are felt by crop and animal producers, food and feed processors.

The ever-increasing number of reports on the presence of mycotoxins in foods and feeds dictates the exigency for practical and economical detoxification procedures. A number of approaches have been taken to counteract mycotoxins, however, only a few have apparent practical applications (Council for Agricultural Science and Technology, 2003).

Which Mycotoxin Deactivation Methods Can Be Used?

As mycotoxins vary considerably within their structural, physical and chemical properties no single deactivation method has been developed to date, but numerous have been tested for their practical application including physical, chemical and biological treatments.

For commercial use, mycotoxin deactivation procedures have to be effective against a variety of mycotoxins, must be simple and inexpensive and should not produce new toxins or alter the nutritional and palatability properties of feed.

Physical Treatments of Crops

If mold infection is not too severe physical treatments that clean the surface or remove heavily infected particular matter can be applied. Washing with water or sodium carbonate solution reduces deoxynivalenol (DON), zearalenone (ZON) or nivalenol (NIV) contamination. Various heat treatments, like autoclaving, roasting or microwave heating may also reduce DON levels to a certain extent. Screens and blowers can be used to separate moldy, fine particulate matter (like dust), or moldy kernels and broken pieces of cobs. Dehulling, polishing and sieving can also help to remove the more toxic portions of feed. Due to their fluorescence properties electronic color sorting can remove kernels contaminated with aflatoxins. Aflatoxin contaminations can also be eliminated by density segregation or flotation, because high toxin concentrations are significantly correlated with low densities. Other physical methods of minor importance are UV radiation and solvent extraction.

However, the efficiency of physical treatments highly depends on the grade of contamination and the distribution of mycotoxins throughout the grain. Subsequently the results obtained are uncertain and often connected with high losses wherefore the practical application is very limited.

Chemical Treatments

Many chemicals have been tested for their ability to decontaminate mycotoxin-containing grain or feed, but only a limited number turned out to be effective against the toxins without diminishing nutritional value or palatability.

To reduce deoxynivalenol concentrations, moist or dry ozone, chlorine gas, ammonium hydroxide, hydrogen peroxide, hydrochloric acid and sulfur dioxide gas have been used. Ammonia treatment combined with heat and pressure decontaminated feed-containing aflatoxins by over 99% and fumonisins up to 79%. Aqueous sodium bisulfite solution decreased aflatoxin and DON contamination. Treatment with calcium hydroxide monomethylamine diminished aflatoxin, T-2 toxin, HT-2 toxin, deoxynivalenol and zearalenone. Formaldehyde destroyed ZON.

However, to achieve adequate decontamination results, parameters such as reaction time, temperature and moisture have to be monitored. In addition to suitable reaction facilities additional cleaning treatments may be necessary, so that chemical procedures may become very time-consuming and expensive.

Treatment of contaminated feed with ammonia was the most attractive method in the past. It was used for example to reduce aflatoxin levels in cottonseed products or in peanut meal. But questions remain about the potential toxicity and carcinogenicity of reaction products. Up to now there is no application of any chemical treatment at a technical scale up.

Diluting Contaminated Grain with Sound Grain

Success of this approach depends on the degree of contamination, the achievable dilution as well as on the availability of a source of suitable, non-contaminated grain. In many cases this strategy is not worth pursuing.

In many countries, deliberate blending of feed containing “undesirable components” (including e.g. aflatoxins) is even prohibited by law.

Reducing Bioavailability by Mycotoxin Chemisorbents

The most widely investigated mycotoxin deactivation method is the addition of chemisorbents with the capacity to tightly bind and immobilize mycotoxins in the gastrointestinal tract of animals, resulting in a major reduction in toxin bioavailability. Activated charcoal for instance is effectively binding ochratoxin A, T-2 toxin and aflatoxins, but concentrations up to 5 to 10% are necessary and essential nutrients are also bound. Other substances investigated as potential mycotoxin-binding agents include alfalfa (for ZON and T-2 toxin), canola oil bleaching clays (for T-2 toxin) and cholestyramin (for ochratoxin A and ZON).

Hydrated sodium calcium aluminosilicate (HSCAS) and bentonites are used for the detoxification of aflatoxin-contaminated feedstuffs. Unfortunately, only certain polar mycotoxins can be removed from

the diet by these adsorbing agents. Their efficacy against zearalenone is very limited and in the case of trichothecenes it is practically zero.

Adsorption properties of minerals are roughly correlated with their total surface area. The higher the porosity of a mineral, the bigger is its surface area and subsequently its general adsorption capability is improved. Besides the total surface area, the pore-size distribution of a porously structured mineral is an important property since it is responsible for the accessibility of this mineral's internal surface, i.e. to allow surface-active sites to bind the desired molecules. Also, preparation methods and chemical treatments can greatly modify their mycotoxin adsorption properties.

Unfortunately, binders found on the market are not all of equal quality and some of them are proposed without any scientific background and quality control. Their composition and mode of action will vary quite a lot. Some of them can even absorb antibiotics, growth promoters, vitamins or essential nutrients, and will cause negative impacts on animals' performance.

Biological Detoxification Of Mycotoxins – A Promising Technique

As several mycotoxins cannot be adsorbed sufficiently by commercially available chemisorbents, alternative methods had to be found.

Bio-transformation of mycotoxins by enzymes and/or microorganisms has been a subject of research for over thirty years. Most of these studies have been using microorganisms found in rumen fluid or in soil. The observation that ruminants are less susceptible to certain mycotoxins than monogastric animals suggested the existence of detoxification processes in the rumen.

The difficult task is not only to be able to identify, but also isolate, characterize and produce at an industrial level the micro-organisms or enzymes that detoxify the toxins. Extensive research work has been published but, so far, only a few studies found practical applications. This biological decontamination may become a technology of choice, as enzymatic reactions offer a specific, efficient and environmentally friendly way of detoxification.

Combination of Selected Adsorbing Agents and Bio-Transformation Methods – an Effective and Economical Way to Control Mycotoxins

The latest generation in mycotoxin-deactivating solutions are products combining adsorbing agents and bio-transformation methods. For example, the following combination is available:

- a bacteria producing specific enzymes that detoxify tricothecenes (such as T-2 toxin) in the intestinal tract of animals (Binder et al., 2000)
- minerals with adsorbing properties, to bind toxins with suitably located polar functional groups (such as aflatoxins)
- a biological constituent which breaks up particular functional groups of less- or even non-adsorbable mycotoxins (such as zearalenone).

We discuss hereafter results of two of the most recent trials conducted with these products on poultry and pigs.

Trial On Broilers In Mexico

This first trial was conducted in 2001 by Dr. Rene Neftali Marquez Marquez in Mexico. The objective was to determine the degree of protection offered by a mycotoxin-deactivating product against in vivo toxicity generated by a synergistically acting blend of mycotoxins.

Mycotoxigenic strains of *Aspergillus parasiticus, Aspergillus ochraceus* and *Fusarium tricintum* were cultivated on corn gluten meal for 8 weeks. Produced aflatoxins (B_1, G_1, B_2, G_2), ochratoxin A and T-2 toxin were quantified by HPLC and mass chromatography.

A 363-factorial design was established: 3 treatments (negative control, positive control and experimental group), 6 birds per treatment and 3 replicates.

Diets (see Table 2) were prepared on a sorghum-soy base, adding the previously contaminated corn gluten meal (for the experimental group and the positive control) and not contaminated corn (for the negative control), respectively. Mycotoxin contamination levels of these diets can be taken from Table 3.

One-day-old chicks, Ross breed, were selected, distributed at random and placed on a Petersime battery cage under controlled temperature. As adapting period, chicks were fed with a commercial diet and water ad-libitum for the first week. Later they were fed with the experimental diets and water ad-libitum to the end of the fourth week.

During the first week, weight gains in all groups were not significantly different, indicating that the toxic effect of mycotoxins was not present yet (see Table 4).

Table 2: Composition and nutritional content of the diets used in the first trial (Broilers in Mexico)

Ingredients (%)	Starter diet (First week)	Grower diet (Second to fourth week)
Sorghum	53.58	63.91
Soybean meal	33.7	18.5
Oil	2.9	4.6
Calcium phosphate	1.7	1.3
Calcium carbonate	1.5	1.2
Chicken meal	0.5	2.0
Feather meal	0.3	1.0
Choline chloride	0.16	0.13
Gromax (anticoccidials)	0.16	0.06
Avelut (Pigment)	0	0.8
Corn gluten meal (60%)	3.0	4.0
Premix*	2.5	2.5
ME (Kcal / kg)	2996	3207
Crude Protein (%)	22.5	19.0
Lysine (%)	1.19	1.02
Methionine + Cystine (%)	1.14	1.06
Threonine (%)	0.82	0.73
Arginine (%)	1.40	1.05
Tryptophan (%)	0.28	0.20
Calcium (%)	1.10	1.01
Available phosphorus (%)	0.52	0.48
Sodium (%)	0.16	0.18

** The premix contains Vitamins, trace-elements, amino-acids, salt and antibiotic growth promoters.*

From the second week on, animals of the toxin group (fed contaminated diets without inclusion of the toxin-deactivating product) showed a constantly decreasing weight gain compared to the control group (no mycotoxins in diet): in week 2 it was reduced to 77%, in week 3 to 67%, to 66% in week four and to only 59% at the end of the trial. This behaviour clearly demonstrates the detrimental and accumulative effect of mycotoxins on animal performance.

Table 3: Mycotoxin contamination levels in diets [µg/kg]

	AB1	AB2	AG1	AG2	OA	T-2	TREATMENT
CG	0	0	0	0	0	0	0
TG	205	55	10	12	290	6300	0
EG	205	55	10	12	290	6300	Mycotoxin deactivator (2.5 kg/t)

CG :control group (negative control); TG: toxin group (positive control); EG: experimental group, treated with Mycofix®'a8 Plus 3.0 (Biomin Laboratory, Singapore) at 2.5 kg/t.

All birds in the contaminated and not protected group (TG) showed beak lesions, necrotic areas on the tongue, ulcers and congested kidneys as well as fatty livers.

Table 4: Weight gain of birds in grams

	week 0	week 1	week 2	week 3	week 4	Total
CG	139^{a}	323^{a}	499^{a}	731^{a}	917^{a}	778^{a}
TG	152^{a}	315^{a}	385^{b}	492^{b}	612^{b}	460^{b}
EG	140^{a}	324^{a}	516^{a}	730^{a}	983^{a}	844^{a}

Different letters (a, b) indicate statistical significance between groups (p<0.05) ANOVA.

Birds fed mycotoxin-contaminated feed including the mycotoxin-deactivating product showed a relative weight gain of 108% compared to the control group, despite the necropsy revealed some lesions and ulcers in the palate of several animals.

These results and the necropsy findings demonstrated that the inclusion of 2.5 kg of the mycotoxin-deactivating product per metric ton of feed to broiler diets contaminated with 282 ppb of aflatoxins, 290 ppb of ochratoxin A and 6300 ppb of T-2 toxin guarantees a high degree of protection against the toxic action of the combined mycotoxins. This data confirm other results such as the ones published by Diaz (2002).

Trial On Pigs In Germany

The objective of this study was first to investigate the effects of long-term exposure to fusariotoxin-contaminated feed on fertility performance and general health of sows as well as on survival rate and growth performance of suckling piglets and second to evaluate the mycotoxin-deactivation capacity of a mycotoxin-deactivating product, aiming at a successful counteraction of these previously mentioned suppressions of performance and health.

Table 5: Group arrangement

		CG[1]	TG[2]	EG[3]
Deoxynivalenol (DON)	[µg/kg]	0	2.500	2.500
Zearalenone (ZON)	[µg/kg]	0	200	200
mycotoxin-deactivating product	[kg/t]	–	–	2.5
No. of sows	n	15	15	15
Reproducing cycles4	n	3	3	3

[1] control group: non-contaminated feed
[2] toxin group: mycotoxin-contaminated feed
[3] experimental group: mycotoxin contaminated feed treated with Mycofix® Plus (produced by Biomin Laboratory, Singapore)
[4] end of trial = weaning of piglets after third lactation

Trial design

The trial was designed to compare performance of a control group (CG) fed low mycotoxin-contaminated feed with two groups of sows fed highly mycotoxin-contaminated diets (TG, EG). For evaluating the effect of the mycotoxin-deactivating product, feed of the experimental group (EG) was additionally supplemented with this additive. Thus, three groups of sows (crossbreed: Landrace Duroc) were formed according to Table 5.

Contrary to the control group, diets of toxin- and experimental group both contained naturally contaminated wheat (see Table 6).

Table 6: Composition [%] and nutrient levels of feeds used in the trial

	Complete feed for gestating sows		Complete feed for lactating sows	
	CG	TG + EG	CG	TG + EG
Wheat	–	15.0 1	45.0	45.0 1
Barley	65.5	50.0	30.0	30.0
Alfalfa meal	20.0	10.0 2	–	–
Molasses	–	16.0 2	–	–
Coarse soybean meal	4.0	5.5	18.0	18.0
Wheat bran	6.0	–	–	–
Vegetable oil	1.0	1.0	3.0	3.0
Mineral premix	3.0	2.0	3.5	3.5
Blend of acids	0.5	0.5	0.5	0.5
Crude protein [%]	13.6 ± 0.9	13.3 ± 0.8	17.2 ± 1.0	17.5 ± 1.1
Lysine [g/kg]	5.6 ± 0.4	5.8 ± 0.3	9.8 ± 0.5	10.1 ± 0.4
Crude fibre [%]	8.5 ± 0.6	7.4 ± 0.9	3.9 ± 0.4	4.1 ± 0.5
Crude fat [%]	3.3 ± 0.5	3.1 ± 0.4	4.8 ± 0.6	5.1 ± 0.4
Energy [ME, kcal/kg]	2585 ± 70	2700 ± 95	3180 ± 95	3200 ± 50

[1] Depending on mycotoxin content of wheat in available bags, 10 to 15% naturally contaminated wheat (DON: 23.8 5.3ppm; ZON: 1.38 0.56ppm; AcDON: 0.22 0.06ppm; nivalenol: 0.46 0.10ppm; fusarenon X: 0.028 0.005) replaced non-contaminated wheat.
[2] From July 2000 , alfalfa meal was replaced by molasses.

Levels of fusariotoxins were mainly oriented by zearalenone, which mimics the effects of estrogen and thus causes severe fertility problems in female pigs. Based on previous data it was decided to target a zearalenone level of 200µg per kg of feed. Since the used naturally contaminated wheat contained a deoxynivalenol-level that was approximately 12 times higher than the ZON-level, a DON-concentration of around 2500µg/kg had to be accepted.

Mycotoxin analyses of finished feed were performed by means of HPLC. Respective results can be taken from Table 7.

Table 7: Actual mycotoxin-content [µg/kg] in used feed

		CG	TG	EG
Deoxynivalenol (DON) :				
no. of analysis	[n]	13	15	15
analyzed content	[µg/kg]	100 ± 102	2564 ± 984	2622 ± 811
Zearalenone (ZON) :				
no. of analysis	[n]	13	15	15
analyzed content	[µg/kg]	30 ± 22	178 ± 52	176 ± 57

Results and discussion

Six sows (out of 16) in the toxin group (highly mycotoxin-contaminated feed without the mycotoxin-deactivating product) did not reach the

end of the 3rd reproductive cycle (see Table 8). Examination results indicated that all 6 animals had to be eliminated from piglet production because of direct toxic aftereffects of present fusariotoxins. In the experimental group, only two animals were lost due to mycotoxin-related effects. Because of unspecific symptoms further three losses could not reliably be assigned to effects of fusariotoxins.

Due to the relatively small number of sows per group, even little deviations from the physiological norm have relatively big effects on fertility-related data. Thus interpretation of respective results given in table 8 is limited.

There was no clear effect of mycotoxins in feed on both total number of born piglets per litter and average birth weight per litter, but the number of underweight piglets (<1.2 kg) was increased in their presence (see Table 9). Addition of the mycotoxin-deactivating product resulted in an improvement of survival rate (TG=32.4% and EG=63.9%).

The number of piglets per litter with zearalenone-induced hyperestrogenism, recognizable by e.g. swelling and reddening of vulva and teats, teat necroses and edema on foreskin of male piglets, as well as the number of animals with splay legs, could significantly be reduced by means of the feed additive (see Table 9).

Moreover, 7 litters of the toxin group contained piglets with extremity-malformation, while only 2 litters of the experimental group presented such problems. Necroses on anal areas and joints occurred in 10 litters of the toxin group, while in the experimental group only 2 litters contained born animals with skin lesions that healed within 6 days.

Within all three reproductive cycles and groups reduction in average daily feed intake of gestating sows occurred only sporadically and limited in time (see Table 10).
However, during lactation feed intake of sows in the toxin group was significantly decreased. Addition of the mycotoxin-deactivating product compensated this suppression almost totally. Compared to the control group, extra feed of 1.4 kg (1st reproductive cycle) and 0.4 kg (2nd+3rd reproductive cycles) per kg of produced piglet was necessary in the toxin group, but only 0.4 kg (1st reproductive cycle) and 0.1 kg (2nd+3rd reproductive cycles) in the experimental group.

Seventy-six percent of all rearing losses occurred

Table 8: Effects of fusariotoxins with or without a mycotoxin deactivating product in feed on fertility characteristics of sows (1st to 3rd reproducing cycle)

		CG	TG	EG
Number of sows	n	15	16	15
Sow losses	n	3	6	5
Number of inseminations	n	38	40	38
Rate of non-conception	n	6	12	7
	%	15.8	30.0	18.4
Weaning to conception (days)	d	9.4 ± 8.5	11.5 ± 10.8	8.4 ± 7.9
Period of gestation (days)	d	114.6 ± 0.9	115.0 ± 1.8	115.0 ± 1.3
Time between farrowings (days)	d	152.5 ± 9.0	154.6 ± 10.6	151.8 ± 9.8
Number of litters	n	38	37	35
Number of weaned litters	n	38	34	35

Table 9: Effects of fusariotoxins and mycotoxin-deactivating product in feed of sows on weight and health of born piglets (1st to 3rd reproducing cycle)

		CG	TG	EG
total number of born piglets per litter	n	12.4 ± 2.0	12.4 ± 2.3	12.7 ± 2.4
birth weight per litter	kg	17.90 ± 3.02	17.12 ± 4.33	18.15 ± 3.83
birth weight per piglet	kg	1.57 ± 0.16	1.56 ± 0.24	1.59 ± 0.22
live born piglets per litter	n	11.5 ± 2.0	11.1 ± 2.6	11.5 ± 2.0
stillbirths per litter	n	0.8 ± 0.7	0.7 ± 1.0	1.0 ± 1.1
piglets born underweight[1]	n	1.9 ± 1.3	2.9 ± 3.1	2.4 ± 2.4
per litter	%	15.1	23.4	18.9
surviving underweight[1]	n	0.9 ± 0.8	0.9 ± 1.3	1.6 ± 1.4
piglets per litter	%	45.6	32.4	63.9
animals per litter with hyperestrogenism	n	0.5 ± 0.8[a]	4.2 ± 1.9[c]	2.2 ± 1.8[b]
animals per litter with splay legs	n	0.7 ± 1.0[a]	4.0 ± 2.4[c]	1.7 ± 1.3[b]
litters with necroses (skin, tail, ear)	n	0	10	2

[1] *<1.2kg live weight*
Different letters (a, b, c) indicate statistical significance between groups (p<0.05) ANOVA.

Table 10: Effects of fusariotoxins and the mycotoxin-deactivating product on feed intake [kg/d] of sows during pregnancy and lactation

	CG	TG	EG
	1st reproductive cycle		
Number of weaned litters	15	15	15
Feed intake during gestation	2.53 ± 0.04	2.50 ± 0.03	2.52 ± 0.03
Feed intake during lactation:			
1st – 28th day	5.50 ± 0.53 b	4.69 ± 0.74 a	5.27 ± 0.57 b
7th – 25th day	6.37 ± 0.69 b	5.18 ± 0.96 a	5.98 ± 0.68 b
Feed [kg] per produced] piglet [kg	5.99 ± 0.59	7.43 ± 1.81	6.44 ± 1.10
	2nd + 3rd reproductive cycles		
Number of weaned litters	23	19	20
Feed intake during gestation	2.53 ± 0.03	2.49 ± 0.06	2.52 ± 0.02
Feed intake during lactation:			
1st – 28th day	5.84 ± 0.57 b	4.69 ± 0.59 a	5.27 ± 0.51 b
7th – 25th day	6.78 ± 0.74 b	5.87 ± 0.80 a	6.50 ± 0.72 b
Feed [kg] per produced piglet [kg]	5.93 ± 0.50	6.34 ± 1.12	6.05 ± 0.80

Different letters (a, b) indicate statistical significance between groups (p<0.05) ANOVA.

during the first week of piglet-life (see Table 11). However, using the additive resulted in higher numbers of weaned piglets per litter and lower losses of piglets during lactation compared to the toxin group. Only a small difference existed between the control and the experimental groups.

The average birth weights of live born piglets were almost the same in all three groups (see Table 9). However, compared to the control group weight gain and weaning weight per litter were significantly decreased in the investigated toxin group (see Table 11).

The decreased number of suckling piglets as well as the reduced feed intake of sows affected lactation performances in the toxin group. On the other hand, by decreasing rearing losses of piglets per litter and by improving feed intake of sows, the mycotoxin-deactivating product had a positive effect on lactation performances.

Table 11: Effects of fusariotoxins and the mycotoxin-deactivating product in feed on rearing and lactation performance (1st to 3rd reproducing cycle)

		CG	TG	EG
Number of weaned piglets per litter	n	10.0 ± 1.6^{b}	8.7 ± 2.2^{a}	9.8 ± 1.7^{b}
Weaning weight per litter	kg	80.74 ± 10.95^{b}	71.23 ± 17.05^{a}	77.17 ± 13.28^{ab}
Weaning weight per piglet	kg	8.18 ± 0.91	8.26 ± 0.91	8.03 ± 0.91
Weight gain per litter	g	65.07 ± 8.95^{b}	57.29 ± 14.19^{a}	61.40 ± 10.62^{ab}
Weight gain per piglet and day	g	236 ± 29	238 ± 31	231 ± 30
Piglet losses during lactation	n	1.5 ± 1.0^{b}	2.4 ± 1.8^{a}	1.7 ± 1.0^{b}
	%	13.0	21.6	15.1
Piglet losses during 1st week of lactation	n	1.1 ± 0.8^{b}	1.8 ± 1.4^{a}	1.2 ± 0.9^{b}
	%	69.5	75.9	70.7
Live weight losses per sow during lactation	kg	15.2 ± 7.1	16.5 ± 9.1	14.9 ± 6.6

Summary and Conclusions.

Mycotoxins are not visible and can be harmful even at very low levels. Proper management during plant growth, harvest and storage are the first steps in the fight against mycotoxins. Physical or chemical treatment of crops give uncertain results and raises questions about safety for the consumer. Their practical application is very limited. Use of binding agents can be effective, provided that their specific mycotoxin adsorption properties are clearly demonstrated. Unfortunately, only certain polar mycotoxins can be removed from the diet by these adsorbing agents. Their efficacy against zearalenone is very limited and in the case of trichothecenes it is practically zero. Biological degradation methods generally offer a gentle, very specific and clean alternative to current detoxification procedures. Enzymatic reactions are irreversible, they leave neither toxic residues nor any undesired by-products and their effectiveness is not confined to adsorbable mycotoxins. Combination of selected adsorbing agents and bio-transformation methods can ensure an effective treatment of contaminated feeds, which results in better performances in both pig and poultry.

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Biosecurity In Feedmill And Swine Farm

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To operate a successful swine operation, it is important to pay special attention to biosecurity. Failing to do so will allow diseases to gain entry into the farm and cause severe economic losses. Biosecurity encompasses every aspect of swine farming which includes: farm management, farm layout, disinfection, pest control, vaccination program, feed production, trucking of feed and feedmill management. Some of the important points to consider in the implementation of biosecurity are:

Location And Design Of Farm To Promote Biosecurity

Planning and design of farm can help to reduce the risks of infection. Farms that lack fencing and changing rooms to quarantine disease, or act as barriers to introduction of disease, will result in disease outbreak. It is therefore necessary to incorporate principles of biosecurity into the design and layout of a farm.

Selecting A Farm Location

Factors such as availability and cost of land, climatic conditions, proximity to feed supply, closeness to the market, determine where farms will be located. Unfortunately, these conditions will attract other producers to locate their farms in the same area, resulting in a high concentration of pigs, representing a single multi-age group, which is conducive to the spread and perpetuation of infections.

It is therefore necessary to have farms physically isolated to prevent transmission of diseases. Distance is one of the most important factor in biosecurity because it limits the use of common vehicles and facilities, inhibits movement of personnel and reduces the spread of disease by vermin, wild birds or wind.

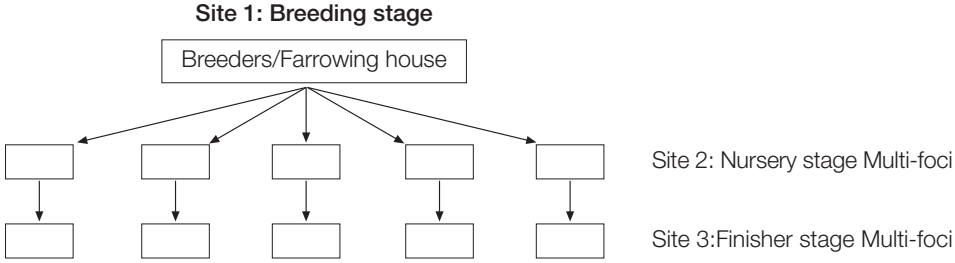
Layout and Design of Farms

To prevent disease transmission, an all-in-all-out (AIAO) management system with multi-site production could be adopted. The AIAO system enables a complete depopulation of the entire unit at the end of each growing period so that a thorough decontamination of the farmhouse can be carried out. This decontamination method will not be possible if the farm is a continuous farrow-to-finish operation.

There are a few versions of the multi-site production system that a producer can adopt, depending on the population of his sows, the availability of land and capital, manpower and management.

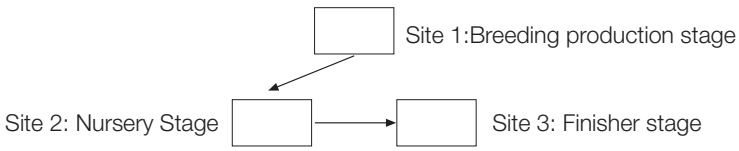
a. Three-Site (Single Source, Multi-Locus) Production

- Pigs are weaned into an all-in-all-out building on a separate location each week.
- Pigs are not mixed from different pens which minimizes social disruption and lateral spread of diseases from older pigs.
- This system requires large sow population of 5,000-10,000 in order to minimize the capital costs per pig produced.



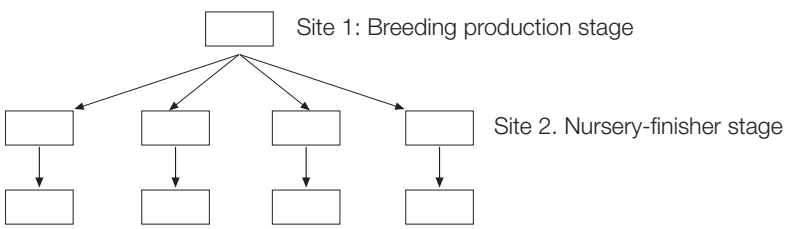
b. Three-Site (Single Source, Single Loci) Production

- Nursery is composed of one or two buildings in one location and finisher buildings are in another location.
- Piglets are weaned weekly at 10-21 days
- Pig flow is all-in-all-out by building at the finisher location.



c. Nurfin (Wean-To-Finish) Production

- Buildings are designed to house finishers but has heater, water drinkers to cater for weaners.
- Pen size can be expanded as the pigs grow.
- Disadvantage: Space is under-utilized when the weaner pigs are housed.
- Advantages: Lower cost of moving pigs and less stress to the pigs when moving from nursery to finisher building, less facilities to be built.



Specific Recommendations For Design Of Farm:

- Access should be limited to authorized visitors and company personnel.
- Farm should not be located near a public road.
- Houses should follow the contour and drainage of the land and with the long axis in an east-west direction to reduce heat gain.
- In farrow-to-finish operations, houses with younger pigs should be located upwind from older pigs.
- Farm should be fenced and houses should be 30 m from the fence line.
- Water supply should be free from pathogens and chlorinated at 2 ppm level.
- Equipment should be kept within a farm.
- Farms should have facilities for change of clothes and shower for farm personnel and visitors.
- All vehicles should be parked outside the perimeter fence. A disinfection pad should be installed to decontaminate feed trucks and other vehicles that must enter the farm.
- Bulk feed tanks should be located adjacent to the fence-line in breeder farms to avoid feed trucks entering the farm. For farms producing commercial porkers, bulk tank can be located adjacent to houses but vehicles should be decontaminated before entering the farm.
- Carcasses should be disposed on-site or have provisions to store carcasses on-site for regular collection.
- Drains should channel water away from houses to a retention area.
- Adequate insulation and ventilation should be provided to reduce stress, which may predispose pigs to infection.
- A closed house or wire netting will act as a physical barrier to prevent entry of wild birds and vermin.
- Walls and doors should be rodent-proofed. Concrete floors are necessary to eliminate rats completely. A rodent-free zone, 60 cm in width and 15 cm in depth, paved with gravels (not more than 2.5 cm in diameter), should be built around the perimeter of farmhouses to act as a barrier to entry of rodents.

- Foot pans or preferably a change of footwear will reduce the transmission of pathogens.
- Filters should be installed to remove particulate material from water lines.

Herd Size of a Farm

The size of the farm has a significant impact on disease control as there are more susceptible animals in a larger herd. In the event of a disease outbreak in a large herd, it would be more difficult to control and the economic loss is greater as compared with a smaller herd. It is therefore better to maintain two sow herds of 500 rather than to have a single farm with 1000 sows.

Introduction Of New Pigs To The Farm

Introduction of new pigs to the farm is the single most important method of bringing in new diseases. It is therefore better to breed your own replacement breeders as it would lessen the chance of introducing new diseases. A closed-herd will generally have less disease problem. If a farm needs to buy replacement breeders, it would be better to buy them from as few farms as possible and these farms should have sound disease control and biosecurity procedures.

Quarantine of New Pigs

It is good practice to separate new pigs in a different building before introducing them to the main herd. The quarantine period should be three to six weeks. If the new pigs have contracted acute diseases, they would have shown the signs during this period. However, if they contracted chronic diseases, they may not show any sign and continue to shed pathogen into the environment. Therefore, quarantine is not a foolproof method to prevent the introduction of diseases.

During the quarantine period, the new arrivals should be dewormed and treated for ecto-parasites (preferably be done at the source). Blood samples should be collected to test for antibodies of Aujeszky's disease, brucellosis and other diseases. As a normal practice, introduce some manure from weaners and mating area to the newcomers. If they have no immunity to the existing diseases in the farm, they will show signs of the disease. If some culled pigs are introduced to the quarantined animals, they may transmit diseases to them or be infected with the diseases that the newcomers are harboring. Therefore, the quarantine animals should be kept in close observation during the period for signs of diseases.

Biosecurity For Manufacture And Distrubution Of Feed

Feed can be a source of infection as it is a common input to all farms. Feed can be contaminated with pathogens derived from feed ingredients or during mixing, delivery or storage.

The quality control department of the feedmill should screen feed ingredients to ensure that they are free from contaminants before delivery to the mixing facility. Animal protein ingredients such as meat and bone meal, poultry by-product meal, fishmeal are high-risk products. Ingredients packed in bags may be responsible for mechanical transmission of disease. Regular microbiological examination of samples of ingredients should be carried out to ensure they are free from *Salmonella spp.* and *Clostridium spp*. In addition, it is necessary to screen corn, wheat, and peanut meal for the presence of mycotoxins as the toxins can cause immunosuppression of pigs rendering them susceptible to infection.

Management and Operation of Feedmills

Feed ingredients delivered to the feedmill should be properly controlled to allow a first-in-first-out (FIFO) inventory management to be carried out. Feed ingredients should be stored properly to prevent cross-contamination of low risk feed ingredients such as soybean meal by high-risk products such as fishmeal and poultry by-product meal. They should be stored in different locations of the warehouse so that they are physically separated to prevent any possibility of cross-contamination.

Silos, storage areas and conveying equipment should be cleaned and maintained to prevent the accumulation of caked ingredients, that cause the development of mold and pathogens, that will contaminate clean ingredients. The area should be dust free so that it will not attract insect pests, and rodents. Feedmill should be equipped with screens to prevent the entry of rodents and wild birds.

Any feed ingredients spilled during unloading should be removed to discourage wild birds and rodents, which serve as reservoir of diseases. The use of pre-conditioner, hygienizer and pelletmill to treat feed with heat will help to eliminate enteric bacteria.

Delivery and Handling of Feed

Feed truck should be thoroughly decontaminated on return to the mill in a designated area to prevent cross-infection. The interior of feed compartment should be clean and dry before being moved to loading bay. Feed bins should be situated in well-drained areas and served by an all-weather road.

Feed bins of farms holding breeding stock should be located next to the fence so that vehicles and mill workers do not have to enter the farms. Specific vehicles are used to deliver the feed to these farms. Farms that are infected with diseases will receive feed last and vehicles and workers have to be decontaminated before returning to the feedmill.

Drivers of feed trucks should be taught the basic principles of biosecurity so that they can appreciate the importance of disease control. They should wear coveralls, footwear and caps provided by the mill. Drivers are not required to enter houses to position augers or unload bags of feed as this should be done by farm workers themselves.

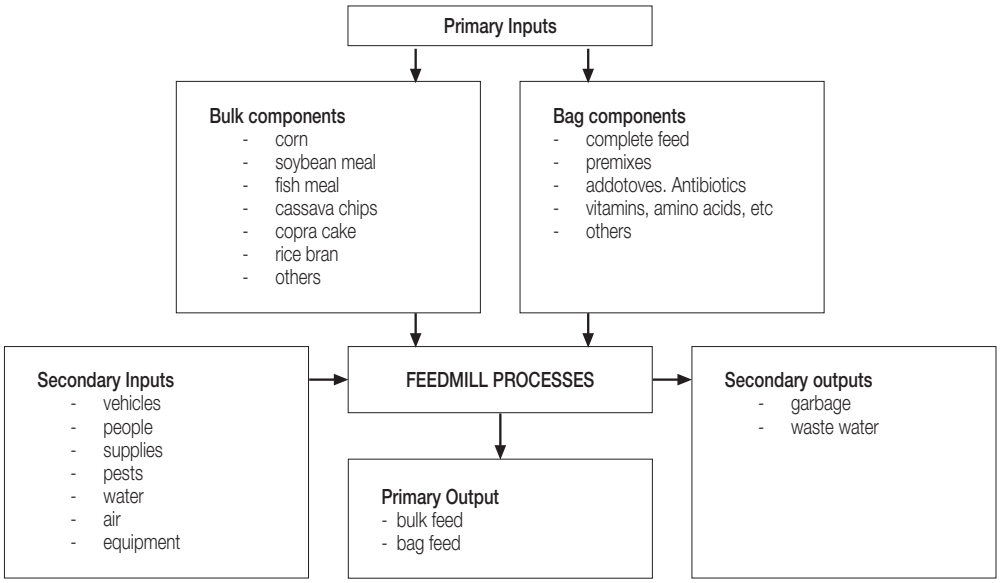
Feedmill Biosecurity Audit

Feedmill biosecurity audit should be done regularly and independently to identify and pinpoint some of the loopholes of the biosecurity measures established by the farm management. It is carried out by following a set of inputs and outputs at the feedmill. Examples of such inputs and outputs are:

1. Primary inputs: feed ingredients, premixes, additives etc.
2. Secondary inputs: vehicles, people, supplies, pests, water, air, equipment.
3. Primary outputs: bulk feed and bag feed.
4. Secondary output: waste water and garbage

Using a flashlight and checklist, the auditor can examine for rodent droppings, poor storage methods, trucking mistakes and other breach of standard operating procedures. He will also evaluate the risk posed by feed ingredients coming into the mill, the delivery system and pest control.

Figure 1. Feed Biosecurity: Schematic of inputs and outputs



Types of Insect Pest

To control insect pest, it is important to identify and classify them. They are divided into two categories, either **internal feeders** or **external feeders**. Internal feeders feed within the kernels and they can damage whole grains, therefore they are more destructive and dangerous of the two. Examples of internal feeders are: Granary weevil, Rice weevil, Lesser Grain Borer and larvae of Angoumois grain moth. External feeders feed on grain dusts, cracked kernels and grain debris, and therefore do not damage whole grain. Examples of external feeders are: Indianmeal moth, Sawtoothed Grain beetle, Red and Confused Flour beetles, Flat Grain beetle, and Cadelle beetle.

Control of Insect Pest

There are many ways that feed ingredients can be infested with insect pests. The source of infestation can be from trucks, combines, wagon auger, grain stored in bin. They can also fly in from the outside if openings of silos and bins are not properly closed. Maintaining good sanitation is therefore important in the control of insect pest. The following practices should be implemented for effective control of insect pest:

- Debris must be removed from equipment such as exhaust, fans and aeration ducts.
- Empty bins must be cleaned thoroughly.
- Vegetation must be cleared three meters around the bins.
- Spray the inside of the bin with residual insecticides such as Malathion 57% EC.
- Spray the outside of the bin from the base up to 5 meters and the soil around it.
- If grain is to be stored for a long period, a grain protectant should be applied at the bottom and top layers while filling up the bin.
- Top dressing with a protectant can be applied if the grain is already in storage.
- Impregnated strips can be used to control insect population. Place one strip for every 28 cu. meters of open space in the bin.

Table 1. Insecticides used for grain protection

Insecticide	Grain	Comment
B. thuringiensis	Corn, soybeans	Top dressing
Primipos-methyl	Corn, sorghum	Grain protectant/top dressing
Malathion	Corn, wheat, sorghum	Wall/top dress/grain protectant
Chlorpyrifos-methyl	Wheat, sorghum	- do -
Pyrethrins & buxtoxide	Corn, wheat, sorghum	Indianmeal moth –adult/larvae
Diatomaceous earth	Corn,wheat,soybeans/sorghum	Empty bins, under slotted floor

Control of Internal Feeders

When grain is infested with internal feeders, it has to be used up quickly or fumigated immediately to prevent further damage. Fumigants are highly toxic and hazardous chemicals therefore fumigation has to be done by certified and trained personnel. It is best to engage professionals to do the job so that the lives of workers will not be endangered. Examples of fumigants are shown in Table 2.

Table 2. Examples of Fumigants

Type of fumigant	Type of grain	Comment
Aluminium phosphide	Corn/wheat/soybeans	Tablets - gas
Carbon dioxide	Corn/wheat/sorghum	Air-tight for 10days
Methyl bromide	Corn/sheat/sorghum	Recirculation is needed, colorless, odorless

Control of External Feeders

Top dressing with protectants can be used to control Indianmeal moth. Aeration and coring can be carried out if the grain is infested with Foreign Grain and Hairy Fungus beetles. In the case of infestation caused by Sawtoothed Grain Beetle, Red and Confused Flour beetle, the removal of grain dust with aspirator and cleaner will deprive them of the source of food.

Infestation by Rodent

Infestation by rodent is a common and serious problem in most pig farms in the region. They are hard to eliminate because of the continuous presence of food, shelter and water available in the farm. They

can cause damage by eating and contaminating feed, destroying insulation, gnawing at building structure, equipment and electrical wires. Inspection is the first step to find out the extent of rodent infestation in the premises. The best time to do it is at dusk and pre-dawn when they are most active. The things to look out for are: droppings, tracks, burrows, pathways, fresh gnawing marks and dead rodents.

Strategy for Rodent Control

There are three approaches for the control of rodent: Sanitation, rodent-proof construction and population reduction.

Sanitation

- Weed control will deprive rodents of a hiding place, nesting materials, food and water. The area around the silo and farmhouses should be free of weed so that any new burrows can be easily detected and dealt with immediately.
- Clean up any grain spillage to deprive rodents of food.
- Remove old equipment, tires and feed bags so that they are not able to nest in them.
- Create a gravel strip around building foundation using 2.5 cm gravel and lay a 60 cm band to a depth of 15 cm deep. This will discourage rodents from burrowing near buildings and use the perimeters as their pathways.

Rodent-Proof the Buildings

Rodents can be prevented from entering buildings if all the openings can be closed. The openings where auger, pipes and wires enter the buildings can be closed with cement mortar. Windows can also be rodent-proof by covering them with heavy gauge wire nettings.

Population Reduction

Reducing the population is one effective way of controlling rodents. Trapping and poisoning with baits are ways to reduce the population.

Snap Traps

They are effective if used properly. Some of the points to follow are:

- Set traps near places where rodents are active such as dark corners, close to walls, top of pallets or on the ceiling.
- For rats, use a piece of salted fish and for mice, use peanut butter as bait.
- Leave traps unset until the baits has been taken at least once. This will reduce the chances of making the rats trap-shy.
- Use enough traps to capture as many rats as possible so that the population can be reduced substantially in a short period. Prolonged trapping will make them trap-shy thus the effectiveness will be lost.
- Set traps 2-3 meters apart for mice as they do not venture far from their shelter. And for rats, set the traps at 3-5 meters apart.

Curiosity Traps

These traps are used for capturing mice because they are curious and will enter traps readily when placed near their nests. These traps can capture a dozen of mice in one evening. Some of the important points to note when using such traps are:

- Traps should be placed flanking the inside of all doorways.
- Place them at openings where utility lines enter the building.
- Place them in areas where mice are seen regularly.
- Service the trap weekly, and make a record of the location and result of each trap so that further trappings can be done in new area.

Rodent Baits

Rodent baits can be divided into two groups namely, anticoagulants and non-anticoagulants. They can be hazardous to other animals when they accidentally consumed the baits and the carcasses

of poisoned rodents. Cats and dogs should be kept away from the area where intensive baiting is being carried out. To avoid accidental poisoning, all outdoor bait containers must be labeled, unused baits must be kept in original containers and stored in locked cabinet. Baits should not be stored with other chemicals as they can absorb their smell and could be rejected by rodents when use later.

Baits continue to be effective if they are kept in containers instead of being left exposed in the open. Baits kept in containers will remain fresh and will not be soiled by dirt, dust and rain. Containers prevent accidental poisoning of non-target animals and allow accurate monitoring of uptake of baits. Baits should be placed near or into the burrows or near their feeding areas or in the pathways between the nest and the food source.

To avoid wasting time and money, only bait burrows that are active. In order to differentiate an active from the inactive burrows, close all the burrows with newspaper and check for opened burrows the next day. Then place containers with baits near the active burrows. Repeat the process daily when baits are taken. Check the burrows 10 days later and repeat the process of identifying active burrows. The whole exercise should last for three weeks until no more baits have been consumed.

Decontamination Of Housing And Equipment

Decontamination is the process of physical removal of biological or inorganic material from surfaces of building or equipment. Disinfection is the destruction of pathogenic organisms adhering to surfaces of buildings, equipment or in biological materials. These two processes are to be done sequentially to destroy pathogens such as bacteria, fungi, and viruses between production cycles.

Decontamination involves the removal of litter and biological material from a house and is followed by the application of detergent solution at high pressure, and then followed by rinsing to remove dirt. Disinfectants work well on previously cleaned surfaces. A program of decontamination and disinfection is shown below:

- **Planning**: Select compatible detergents and disinfectants, obtain suitable pumps, applicators, protective clothing, and recruit properly trained workers.
- **Execution**: Remove debris and waste followed by application of detergents and disinfectants.
- **Monitoring**: Inspect premises to ensure it is clean and free from pathogens after cleaning.

The following disinfectants are used:

- **Cresols:** They are derived from petroleum distillates. They have broad virucidal and bactericidal action against gram (+) and gram (-) organisms. They are suitable for use for earthen floor as they are soluble in diesel fuel. Cresol has an unpleasant odor and will taint eggs and other food products. Therefore it is not suitable in areas where food products and eggs are handled.
- **Phenols**: They are derived from coal tar and are virucidal but more active against gram (+) and gram (-) organisms. Bisphenols are active against fungi and have prolonged residual action. They are usually applied in solutions containing 1-3% of active ingredient.
- **Iodophors**: These compounds contain iodine. They are active against viruses and both gram(+) and gram(-) organisms, with long residual effect. At 100-150 ppm, iodophors are effective in hatcheries or for decontamination of smooth surfaces and equipment. Their use is limited by cost, staining and in some formulations, corrosion.
- **Quaternary Ammonium compounds (QAC)**: These compounds contain a quaternary ammonium nucleus with an N-alkyl chain ranging from 6-16 carbons. They are active against viruses and gram(+) and gram(-) bacteria. QACs can be used together with non-ionic detergents.
- **Chlorine compounds**: Chlorine is usually in the form of sodium hypochloride. Chlorine compounds are inactivated by organic material and sunlight and require a low pH value for activity. Chlorine is used at level of 2 ppm to disinfect water. At level of 500-2,000 ppm, chlorine compounds are effective disinfectants. Tainting and corrosion will occur above 100 ppm.
- **Formalin**: Formalin and formaldehyde gas are corrosive and carcinogenic. Their use is on the decline and workers using them should have proper training and wear protective clothing, including respirators.

Disinfection of Buildings

- Loose equipment should be disassembled and components removed from the house for cleaning and disinfection.
- All electrical units should be sealed after dust is removed with air line.
- The building should be decontaminated with a non-ionic detergent solution at 200-500 psi at recommended concentration. Spraying of the exterior should be in this sequence: roof, exterior walls, drains, and service area.
- Remaining feed should be removed from bulk bins and feed bins should be decontaminated and allowed to drain and dry.
- The interior of the building should be pressure-sprayed with disinfectant in the following sequence: ceiling, walls, curtains, equipment, and concrete floor from back to front.
- The interior structure and equipment should be rinsed with water. Remaining detergent solution should be used to flush into the drainage system.
- The interior of the house should be sprayed with disinfectants at a concentration recommended by the manufacturer.
- Equipment should be reassembled, and routine preventive maintenance and adjustments should be carried out. All systems should be tested.
- Rodent bait should be placed in selected areas of the house.
- Water lines and drinkers should be drained and cleaned. A concentrated chlorine solution (1.0 liter of 6% chlorine per 50 liters of water) can be pumped through the drained water lines and allowed to stand for 24 hours. The lines are then cleaned and dried. Use an air line to remove debris.

Conclusion

Biosecurity in pig farming is an important input in the production cycle. It involves farm management, farm layout, disinfection, pest control, vaccination program, movement of pigs, feed ingredient storage and production, storage and trucking of feed. The farm manager and workers should be aware of the importance of biosecurity in preventing diseases from entering the farm. Special precaution should be taken in the introduction of breeding stock. Quarantine of newcomers is essential but it is not 100% effective in preventing the introduction of diseases to the farm. Feedmill security audit should be carried out on a regular basis so that any breaches in the biosecurity could be quickly rectified. A multi-site production and AIAO management of pigs should be adopted to minimize the exposure to pathogens and ensuring the thorough disinfection of the premises after each batch of pigs.

To maintain strict biosecurity, it requires the cooperation of everyone working in the farm and those who are related to the business, such as feed and animal health product suppliers, pig traders, veterinarians, farm consultants, etc. The onus is on the farm owner to put in place the necessary procedures to ensure that there is no leakage in the defense line. Failure to do so will result in severe outbreak of diseases that could have a disastrous effect on his farming business.

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Covered Lagoons For Biogas Utilization In Swine Production

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Introduction

With increase in public awareness of environmental degradation, waste management has become an important component of swine production. In some countries, it has become a critical component that determines the continued existence of the farm. In most developing countries, the first attempt to manage swine waste has been the use of waste stabilization ponds, or something resembling that. The main reason has been the relatively inexpensive cost of land in these countries. However, the use of waste ponds suffers from various disadvantages such as: a) incorrect design and sizing results in problems like short-circuiting, presence of stagnant zones, stratification and insufficient retention time (Ong, 1998); b) the abuse of ponds results in death of micro-organisms and subsequent non-functioning; c) emission of greenhouse gas (GHG) and odours. The good point about the use of waste stabilization ponds is that it gives plenty of opportunities for stage-by-stage improvement of waste management in accordance with national regulations as well as farmers' experience. In this paper, a case is put up for upgrading of anaerobic ponds to become covered lagoons to capture biogas, which is converted to electricity for the purpose of running closed-house production units.

Covered anaerobic lagoon

Designed waste stabilisation ponds are usually a series of anaerobic, facultative and aerobic ponds. The first pond is typically anaerobic, with a depth of at least 2 m. The main purpose of this pond is the stabilisation of organic matter. Decomposition of organic matter is carried out by anaerobic bacteria in stages. Typically, it can reduce BOD (Biochemical Oxygen Demand) by up to 80%. The final products of anaerobic digestion are methane, carbon dioxide and various other gases, which give rise to mal-odour. These gases, collectively called biogas, are produced in the anaerobic pond, which acts as an anaerobic digester. The main component of the biogas is methane (about 60%), which is a source of renewable energy. An irony exists in this type of situation in many swine production units in the tropics. On the one hand, odorous gases are continuously being emitted to the atmosphere, inviting nuisance complaints from neighbours. Furthermore, the major component of these gases, i.e. methane is 21 times more potent than carbon dioxide in terms of global warming potential. On the other hand, swine production is quite energy-intensive, requiring energy for pumping, grinding, mixing, heating piglets, cooling heat-stressed pigs, etc. If the anaerobic pond is covered by an impervious material such as high density polyethylene or red mud plastic, the methane could be captured for generating extra electricity to be used within the farm. This would lead to two benefits, namely improved pig productivity and reduced mal-odour. Thus, there is synergy between appropriate waste management and improved pig production.

Area of lagoon

Appropriate lagoon size is dependent on: a) daily slurry volume; b) retention time; c) depth of lagoon. Slurry volume can be estimated by measuring the flow rate over a measured stretch of drain in which the slurry drains into the lagoon and obtaining the cross-sectional area of drain. For anaerobic digestion, the minimum retention time should be 10 days, preferable longer, e.g. 15 days. An example of size estimation is shown in Table 1. Once the total volume is known, the area

Table 1. Sizing of anaerobic lagoon

Parameter	Value
Slurry volume	30 L/SPP/day
Total Standing Pig Population (SPP)	1000
Total slurry per day	30 m^3
Retention time	15 days
Total required volume of lagoon	450 m^3
Depth of lagoon	2.5 m
Area of lagoon	180 m^2

is obtained by dividing volume by depth. In this example, the area of lagoon is 180 m^2 (e.g. 10 x 18 m). Note that the area of the cover material should be generously larger that calculated value, considering that the cover materials are typically buried into the soil all around the lagoon and there must be headspace for gas collection.

Table 2. Estimation of biogas production from pig slurry

Parameter	Value
Standing pig population (SPP)	1000
Slurry volume per SPP	30 L/day *
Total slurry volume per day	30 m^3
% total solids (TS) in slurry	5
TS/day	1500 kg
% total volatile solids (TVS) in TS	80
TVS/day	1200 kg
Volume of biogas /kg TVS/day	0.3 m^3
Volume of biogas/day	360 m^3

** Based on survey of Teoh et al. (1988)*

Estimation of biogas production from pig slurry solids

Production of methane from a pig farm of a known size can be estimated from the slurry characteristics, as shown in Table 2. This is based on the fact that biogas are converted from total volatile solids (TVS) in the slurry. Under experimental conditions, 0.3 m^3 biogas per kg TVS per day had been obtained. In terms of gas production per day and electricity output per animal per day, Table 3 can be used as a guide for estimation based on actual farm conditions, although these are figures obtained under temperate climatic conditions. Biogas production can be affected by numerous factors such as: a) temperature; b) pH of slurry; c) salinity; d) nutrient concentration; e) inhibitory substance; f) rentention time; g) loading rate; h) hydraulic properties and i) sub-soil permeability.

It is estimated (Polprasert, 1989) that one m^3 of biogas is sufficient to:

a. run a one-HP engine for 2 hours;
b. provide 1.25 KW-H of electricity;
c. provide heat for cooking three meals a day for five people;
d. provide 6 hrs of light equivalent to a 60-Watt bulb;
e. run a refrigerator of 1 m^3 capacity for one hour.

Based on those assumptions, production of biogas from a 1000-SPP farm can potentially generate roughly 420 KW-H of electricity per day. In terms of kWh/head/day of animal category, Table 3 can be used as a guide (www.rcmdigesters.com).

Table 3. Estimation based on on-farm monitoring (temperate climate)

Animal category	Litres Biogas/day	kWh/head/day	No. needed for 40 kW generator
Sow	170	0.25	3,200
Weaner	50	0.08	11,000
Grower-finisher	125	0.18	4,400
Laying hen	7	0.01	72,000
Beef cattle	1400	2.0	600
Dairy cow	2000	3.1	400

Source: www.rcmdigesters.com

Biogas purification

Depending on the factors affecting biogas production, the composition of biogas may be variable. However, the composition is usually within the ranges shown in Table 4.

Table 4. Composition of biogas

Gas	% Content
Methane (CH4)	55-65
Carbon dioxide (CO2)	35-45
Nitrogen (N2)	0-3
Hydrogen (H2)	0-1
Hydrogen sulphide (H2S)	0-1

The desired gas is methane, which is the actual fuel. The most undesired gases are carbon dioxide and hydrogen sulphide. Carbon dioxide can be removed by passing biogas through an alkaline solution, such as lime or calcium hydroxide. A mixture of 1 kg of lime in 1 m^3 of water can remove 300 litres of CO_2. For daily production of 56 m^3 of biogas, 20 m^3 of CO_2 needs to be removed, requiring 65 kg of lime. Calcium carbonate would be precipitated out and must be removed from the solution. Alternatively, CO_2 can be removed by water

scrubbing, since CO_2 is fairly soluble in water. Some 277 litres of water is required to scrub 1 m^3 of biogas. H_2S can be removed by passing biogas over iron fillings or ferric oxide (Fe_2O_3) mixed with wood shavings. Passing biogas over a drum having layers of such mixtures can effectively scrub H_2S. Water vapour in biogas can be removed by chemical absorption or by having some condensation traps.

Use of biogas on engines

Methane gas in biogas has the potential to substitute natural gas (propane and butane) as a fuel for engines under correct conditions.

Gasoline engines

For gasoline engines, no conversion of engine is necessary. It is like the "conversion" of petrol engines to natural gas engine. What is required is the installation of a gas-air mixer preceding the carburettor. A butterfly air valve controls the flow of air while a gas tap controls the flow of gas. A suitable adapter containing both these controls can be fitted by means of a collar in place of the air filter, or the air filter can still be fitted over the butterfly valve. The engine is first started on petrol. After a warm-up period of a few minutes the petrol supply is cut off, while the gas tap is opened slightly and the air valve is closed gradually until the engine runs normally. For smooth running of the engine, the gas should flow at a steady pressure.

Diesel engines

It is normally simpler to convert a diesel engine into a duel-fuel engine using both the liquid diesel and mixed fuel, i.e. biogas-diesel. The gas provides the main fuel instead of the diesel, with a small amount of liquid diesel being required to ignite the compressed mixed gas (methane-air). In case the gas fuel is not enough, it can be switched to liquid fuel to run the engine normally. The conversion of the intake system can be made by installing an extra mixing device at the rear of the air-filter. The mixer consists of a valve controlling the quantity of biogas and a three-way pipe. Thus the components should include the air filter, the mixed gas, the intake pipe, biogas choke and the exhaust pipe. The engine is started with diesel, keeping the biogas choke shut. After starting, the biogas choke is slowly opened to let in the gas. The choke would need to be manipulated in response to varying engine speed until it runs smoothly.

Generator

By the same reasoning, the combined use of a modified diesel engine, a synchronous generator and heat recovery system, the farm could be more than self-sufficient in energy requirement. Gensets run on biogas is commercially available. Some companies provide gensets modified from used diesel or petrol engines.

Case studies

Table 5 summaries the key data of some farms that have been documented among numerous other cases as having successfully generated electricity from biogas produced from animal waste.

Evaporatively cooled closed barns

Heat stress is a major constraint in pig and poultry production in the tropics. Pigs and poultry are both homeothermic, i.e. they maintain a relatively constant temperature. In the case of pigs, the average body temperature is 39.2°C but it can range from 38.7 to 39.4°C. An increase in body temperature of only a few degrees above the average can be very damaging and even fatal. Internal body temperature is controlled by a dynamic equilibrium between heat produced and heat gained from or lost to the environment. Baby pigs do not have a well developed homeothermic system; thus they must be protected against chilling during the first few weeks after birth. This protection could also be provided by radiant heaters run on biogas. Although pigs have functional sweat glands associated with hair follicles, they are unable to sweat effectively for thermoregulation and therefore hyperventilate to increase respiratory heat loss (breathing rapidly). Respiratory evaporative heat loss alone is not sufficient when the ambient temperature exceeds 30°C and the pig has to create artificial sweat by wallowing in any available water (wet surface, mud, urine) to allow surface evaporative loss. Evaporative heat loss, therefore, plays a major role at high ambient temperatures (Shanmugavelu, et al, 2002).

Table 5. Data of some case studies

No.	Farm Location	Farm Type (standing heads)	Herd Size Capacity, m^3	Digester Production, m^3/day	Biogas Production, kWh/day	Electricity
1	Foster Brothers Farm, Middlebury, VT, USA	Diary cows	635	900 (tank system)	790	1200
2	Corneche, Chile	Finishing pigs	102,000	N/A (Lagoons with HDPE cover)	N/A (Biogas is flared; owner only interested in reducing odor)	Nil
3	Martin Farm, South Boston, VA, USA	Farrow to feeder swine	6000	N/A (Lagoons with XR-5 experimental cover)	397 (170 in winter)	600
4	Royal Farms, Tulare, CA, USA	Farrow to finish swine	16,500	30,000 (Lagoons with hypalon cover)	1982	1900
5	Brendle Farms, Somerset, PA, USA	Caged layers	75,000	550 (Tank system)	790	1000
6	Darrell Smith Farm, Princeton, NC, USA	Caged layers	70,000	595	1189 (summer)	820
7	Barham Hog Farm, Zebulon, NC, USA	Farrow to weaners swine	4,000 sows	N/A (Lagoon with HDPE cover)	632	180 (Biogas also used to run a 400,000 Btu boiler)
8	Perallillo, Chile	Finishing swine	120,000	N/A (more 80 acres of lagoons)	10, 200 to 15,500	Nil (mainly for odor control; gas is flared)
9	Tohoku Farm, Aomori, Japan	Farrow to finish swine	30,000	N/A (tank system)	N/A	Generated electricity but figure not revealed)

Sources: 1) Lusk, 1988; 2) Moser, 2005

Gilts and sows are adversely affected by temperature above 30°C. Heat stress due to such a condition would delay oestrus, reduce ovulation and increase embryonic deaths. Boars subjected to heat stress of one degree rise in body temperature would have a reduction in semen quality for 4 to 8 weeks. Females bred to such a boar during that time could expect a lower conception rates and smaller litters.

The principle means of dissipating heat from pig barns is by air exchange. Many factors affect such a process, e.g. radiation heat load, roof shape, height and spacing, roof material, barn orientation, etc. Many pig producers could not control all of those factors, especially when they have old buildings to work with. The potential of extra energy being generated on the farm offers another possibility, i.e. to utilize the renewable energy for powering an evaporatively cooled closed house for the animals. This involves the installation of cool pads on one side of the barn, a large fan that blows air across the barn and curtains on the other three sides of the barns. As moisture on the cool pads evaporates, the barn is cooled. If improved breeds originating from temperate countries are used under humid, tropical conditions, the provision of thermal-neutral environment would increase productivity.

Conclusion

The most common method of waste management in pig farms in developing countries is the use of various forms of waste stabilisation ponds. It is by far the cheapest way of waste treatment if land area is relatively inexpensive. However, the use of ponds suffers from several disadvantages, the chief

of which is the emission of greenhouse gases and odours. Biogas is continuously being emitted from anaerobic lagoons. The major proportion of biogas is methane, which is a fuel. Therefore it is beneficial to make use biogas as a renewable energy in the management of pig waste, utilising synergistic approaches for maximum productivity and minimal generation of wastes. A step forward in this direction is the upgrading of the first anaerobic pond into a biogas digester, which produces methane, which generates energy for use in productivity improvement such as the cooling of pig barns. An added benefit of this approach is the abatement of greenhouse gases as well as odour.

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Importance Of Vermin Control And Housekeeping In Feedmills

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Introduction

Vermin infestation is a serious problem that has plagued the feed industry in the region for a long time. Hot and humid tropical environment, dusty conditions, availability of food and poor housekeeping allow vermin to thrive all year round. Some feedmill operators have tried to control them but failed and accepted the presence of vermin as part and parcel of feedmilling. However, with greater awareness of food safety, the feed industry will have to find a solution to this problem, so that consumers can be confident of what they eat. After all, feed is one of the components of the supply chain in food production.

In fact, insects and rodents are not as harmless as we think. They can damage feed ingredients by causing hotspots, reducing weight of grain and its nutritional values. They can also contaminate, change the odor, and cause mold problems to feed ingredients and finished feed. Large population of rodents can consume considerable amount of feed and feed ingredients over a long period. Furthermore, rodent waste could be a source of transmission of disease such as leptospirosis, which can infect human being and animal.

In reality, infestation can be controlled if one is determined enough to take the necessary actions. The objective of this paper is to provide strategies to tackle the vermin problem in feedmills.

Type of Insect Pests

Insect pests can be classified into two categories. They are either internal feeders or external feeders. Internal feeders feed within the kernels and they can damage whole grains, and therefore are more destructive and dangerous of the two. Examples of internal feeders are: Granary weevil, Rice weevil, Lesser Grain Borer and larvae of Angoumois grain moth.

External feeders feed on grain dusts, cracked kernels and grain debris, and therefore will not damage whole grain. Examples of external feeders are: Indianmeal moth, Sawtoothed Grain beetle, Red and Confused Flour beetles, Flat Grain beetle, and Cadelle beetle.

Another category comprises the Foreign Grain beetle and Hairy Fungus beetle. They feed on molds and fungi growing on grains. By monitoring their population, the severity of mold infestation in the grain can be gauged.

Control of Insect Pests

Feed ingredients can be infested with insect pest in many ways. The source of infestation can be from truck, combines, wagon auger, grain in bin. They can also fly in from the outside if openings of silos and bins are not properly closed. Maintaining good sanitation is therefore important in the control of insect pests. The following practices should be implemented for effective control of insect pest:

- Debris must be removed from equipment such as exhaust, fans and aeration ducts.
- Empty bins must be cleaned thoroughly.
- Vegetation must be cleared three meters around bins.
- Spray the inside of the bin with residual insecticides such as Malathion 57% EC
- Spray the outside of the bin from the base up to 5 meters and soil around it.
- If grain is to be stored for more than one year, a grain protectant can be applied at the bottom and top layers while filling up the bin.
- Top dressing with a protectant can be applied if grain is already in storage.

- Impregnated strips can be used to control insect population. Place one strip for every 28 cu. meters of open space in the bin.

Table 1. Insecticides used for grain protection

Insecticide	Grain	Comment
B. thuringiensis	Corn, soybeans	Top dressing
Primipos-methyl	Corn, sorghum	Grain protectant/top dressing
Malathion	Corn, wheat, sorghum	Wall/top dress/grain protectant
Chlorpyrifos-methyl	Wheat, sorghum	- do -
Pyrethrins & buxtoxide	Corn, wheat, sorghum	Indianmeal moth –adult/larvae
Diatomaceous earth	Corn,wheat,soybeans/sorghum	Empty bins, under slotted floor

Control of Internal Feeders

When grain is infested with internal feeders, it has to be used up quickly or fumigated immediately to prevent further damage. Fumigants are highly toxic and hazardous chemicals therefore fumigation has to be done by certified and trained personnel. It is best to engage professionals to do the job so that lives of workers will not be endangered. Examples of fumigants are shown in Table 2.

Table 2. Examples of Fumigants

Type of fumigant	Type of grain	Comment
Aluminium phosphide	Corn/wheat/soybeans	Tablets - gas
Carbon dioxide	Corn/wheat/sorghum	Air-tight for 10days
Methyl bromide	Corn/sheat/sorghum	Recirculation is needed,
		colorless, odorless

Control of External Feeders

Top dressing with protectant can be used to control Indianmeal moth. Aeration and coring can be carried out if grain is infested with Foreign Grain and Hairy Fungus beetles. In the case of infestation caused by Sawtoothed Grain Beetle, Red and Confused Flour beetle, the removal of grain dust with aspirator and cleaner will deprive them of source of food.

Sanitation, Loading, Aeration & Monitoring Strategy (S.L.A.M.)

This is a long-term strategy that can be used to maintain the quality of grain in storage. The strategy comprises four parts:

Sanitation – is maintained by cleaning grain dust and fine material in bin, aeration ducts, floors, auger trenches. Remove weeds and trash so that they will not shelter insects. Spray insecticide around the perimeter of bin and the outside wall up to 1-1.5 meters from the base.

Loading – involves cleaning of grain, coring the content of bin and leveling the surface of grain at the top layer. This will remove fines from the bin found at the core thus preventing insect to have access to them. Removing fines from the core will also remove some insects as that is where they are likely to concentrate. Aeration will improve when fines are removed.

Aeration – Keep grain temperature below the feeding and breeding temperature ranging from 21 – 32°C by using aeration fan and / or grain chillers. When the temperature is attained, fans have to be sealed off to prevent escape of cold air and entry of insects.

Monitoring – Monitor the temperature of grain with a thermocouple, take grain and insect samples at regular intervals, and if hot spots are detected, proceed with aeration or grain turning.

Infestation by Rodents

Mouse and rat are found in feedmills because the presence of food, shelter and water. They can cause damage by eating and contaminating feed, destroying insulation, gnawing at building structure, equipment and electrical wires.

Inspection is the first step to take to find out the extent of rodent infestation in the premises. The best time to do it is at dusk and pre-dawn when they are most active. The things to look for are: rodents, droppings, tracks, burrows, pathways, fresh gnawings and dead rodents.

Strategy for Control of Rodents

There are three approaches for the control of rodent: Sanitation, rodent-proof construction and population reduction.

Sanitation

- Weed control will deprive rodents of hiding place, nesting materials, food and water. The area around the silo should be free of weed so that any new burrows can be easily detected and dealt with immediately.
- Clean up any grain spillage to deprive rodents of food.
- Remove old equipment, tires and feed bags so that they are not able to nest in them.
- Create a gravel strip around building foundation using 2.5 cm gravel and lay a 60 cm band to a depth of 15 cm deep. This will discourage rodent from burrowing near building and use the perimeters as their pathways.

Rodent-Proof the Building

- Rodents can be prevented from entering buildings if all the openings can be closed. The openings where auger, pipes and wires enter the building can be closed with cement mortar. Windows can also be rodent-proof with heavy gauge wire netting without impeding ventilation.

Population Reduction

Reducing the population is one effective way of controlling rodents. Trapping and poisoning with baits are ways to reduce the population.

Snap Traps - is effective if used properly. Some of the points to follow are:

- Set trap near places where rodents are active such as dark corners, close to walls, top of pallets or on the ceiling.
- For rat use a piece of salted fish and for mice use peanut butter as bait.
- Leave traps unset until baits has been taken at least once. This will reduce the chances of making the rats trap-shy.
- Use enough traps to capture as many rats as possible so that the population can be reduced substantially in a short period. Prolonged trapping will make the trap-shy thus effectiveness will be lost.
- Set traps 2-3 meters apart for mice as they do not venture far from their shelter. And for rat set the traps at 3-5 meters apart.

Curiosity Traps - These traps are used for capturing mice because they are curious and will enter traps readily when placed near their nests. These traps can capture a dozen of mice in one evening. Some of the important points to note when using such traps are:

- Traps should be placed flanking the inside of all doorways.
- Place them at openings where utility lines enter the building.
- Place them in areas where mice are seen regularly.
- Service the trap weekly, and make a record of the location and result of each trap so that further trapping can be done in new area.

Rodent Baits

Rodent baits can be divided into two groups namely, anticoagulants and non-anticoagulants.

Table 3. Examples of Rodenticides

Type of Rodenticide	
Botanical R.	Scilliroside, strychnine
Coumarin R.	Warfarin, brodifacoum, coumachlor, difenacoum
Indandione R.	Chlorophacinone, diphacinone, pindone
Inorganic R.	Sodium arsenite, zinc phosphite, thallium sulfate, phosphorus
Organochlorine R.	Gamma-HCH, Lidane
Organophosphorus R.	Phosacetim
Pyrimidinamine R.	crimidine
Urea R.	Pyrinuron
Unclassified R.	Hydrogen cyanide, bromethalin, ergocalciferol, fluoroacetamide

Anticoagulant Rodenticides: These products block the production of vitamin K-dependent coagulation factors by inhibiting the enzymes responsible for recycling of vitamin K. The lack of coagulation factors causes the animal to bleed to death because the blood does not clot.

Bromethalim: It works by affecting the permeability of the cell membranes resulting in the cell swelling and losing function. Signs are related to central nervous system (CNS) dysfunction. Bromethalin poisoning should be considered whenever acute signs of cerebral edema or paresis or paralysis of the hind limbs are seen. Death is usually caused by respiratory paralysis.

They can be hazardous to other animals when they accidentally consumed the baits and the carcasses of poisoned rodents. Cats and dogs should be kept away from the area where intensive baiting is been carried out. To avoid accidental poisoning, all outdoor bait containers must be labeled, unused baits must be kept in original containers and stored in locked cabinet. Baits should not be stored with other chemical as they can absorb their smell and could be rejected by rodents when use later.

There are advantages if baits are kept in containers instead of been left exposed in the open. Baits kept in containers will remain fresh and will not be soiled by dirt, dust and rain. Containers prevent accidental poisoning of non-target animals and allow accurate monitoring of uptake of baits. Baits should be placed near or into the burrows or near their feeding area or in the pathways between the nest and source of food.

In order not to waste time and money only bait burrows that are active. To differentiate an active from the inactive burrows, close all the burrows with newspaper and check for opened burrows the next day. Then place containers with baits near the active burrows. Repeat the process daily when baits are taken. Check the burrows 10 days later and repeat the process of identifying active burrows. The whole exercise should last for three weeks until no more bait has been consumed.

Conclusion

Vermin control in feedmills is a continuous battle that requires discipline and tenacity. Its success depends on desire on the part of the management wanting to make the premises pest-free. Monitoring and baiting should be done regularly so that the population is kept in check and not allowing to be multiplied beyond control.

Making the feedmills rodent-proof and closing all openings to prevent the entry of insect pest will keep the premises free from them. Feedmills should have a weekly schedule to carry out maintenance of machinery and at the same time to clean up grain dust and spillage to deprive food source for vermin. The practice of S.L.A.M. will ensure that insect pest can be kept to a minimum. Storing feed ingredients in bulk bins and silos will further help the effort, as it is much easier to treat, aerate and fumigate infested content than those kept in bags or on flat storage. Furthermore, silo wall creates a strong physical barrier to prevent vermin to have access to the content.

The enemy is not going to sit still. If we want to emerge as the winner in this battle we have to be on our guard all the time and implement the strategies provided earlier. The dividend will be in the form of reduction in damaged grain, machinery, better quality feed produced and a healthy and pleasant working environment that we can be proud of.

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Pest Management In Feedmills

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Several proprietary product names were mentioned in this chapter. The author and Kansas State University do not endorse or recommend these products at the exclusion of other similar products.

Introduction

Several stored product insect and vertebrate pests (rodents and birds) are associated with feed manufacturing plants. The types of pest species found in feed manufacturing plant may vary depending on the geographic location of the plant, type of feed ingredients handled, and levels of sanitation and pest management. Irrespective of the type of species found, a basic knowledge of pest biology, ecology, and behavior is essential for developing and implementing effective pest management programs. The main objective of pest management is to maintain pest populations at levels where they do not cause aesthetic or economic loss.

Various aspects of the feed manufacturing plant, such as ambient temperature, type of ingredients used, processing of the ingredients, equipment design, sanitation schedules, level of sanitation, and level of pest management have an impact on the incidence, distribution, and abundance of insect and vertebrate pests. Plant conditions, such as warm temperatures year-round in production areas, accumulation of grains or grain residues inside equipment, and availability of raw and finished materials of plant or animal origin, are conducive for supporting insect and vertebrate pest infestations. The susceptibility of various feed materials to pests, and the impact of manufacturing plant operations and conditions on pest infestations, should be clearly understood to develop practical pest management programs.

This chapter provides an overview of the identifying features, biology, ecology, and behavior of commonly encountered, and economically important, insect and vertebrate pests infesting cereal grains, feed manufacturing plants, and feed products. Much of the information presented here has been summarized from various reference books (Baur 1984, Slansky and Rodriguez 1987, Mills and Pedersen 1990, Gorham 1991, Haines 1991, Sauer 1992, Subramanyam and Hagstrum 1995a, Hedges and Lacey 1996, Bennett et al. 1997, Subramanyam and Hagstrum 2000), and from authors' research and practical experiences. These references are an invaluable source of information on insect and vertebrate pests and their management, and should be consulted for in-house training of plant employees and for developing customized pest management programs.

Stored Product Insects

The exact origins of stored product insects are unknown. They are assumed to be tropical or subtropical in origin, because of their ability to thrive well under warm conditions. Insects associated with stored food products primarily belong to three insect orders: Coleoptera, which includes the beetles; Lepidoptera, which includes the moths; and Psocoptera, which includes the psocids or booklice. Members of about 40 beetle families are associated with stored foods. However, only members belonging to seven families are considered economically important. These families are Bostrichidae, Bruchidae, Curculionidae, Dermestidae, Laemophloidae (previously Cucujidae), Silvanidae, and Tenebrionidae. Both adults and larvae of beetles cause damage to stored products. About 70 species of Lepidoptera belonging to the families of Pyralidae, Tineidae, Oecophoridae, and Gelechiidae have been reported in various stored food products. Of these families, a few members of Pyralidae are frequently encountered infesting cereal grains, feed plants, and feed products. Unlike beetles, only the larval stages of moths cause damage to stored products. The order Psocoptera consists of very small insects, no larger than a pinhead (0.03-0.24 inch), that are capable of causing severe damage to stored grains. There are about 15 species of psocids associated with stored products.

Insect pest infestations in feed manufacturing plants can reduce quality and quantity of infested materials, result in increased customer complaints, cause allergic reactions in sensitive workers handling infested products or in animals feeding on the infested commodities, damage packaging materials, contaminate finished products, and clog machinery (e.g., webbing by moth larvae) resulting in unnecessary downtime. Furthermore, frequent infestations could increase pest management costs and lead to loss of consumer confidence.

General Identification Features

The insect body is divided into head, thorax, and abdomen (Figure 1). The head is a sensory structure that has eyes, mouthparts, and a pair of antennae. The thorax has three pairs of legs and (usually) two pairs of wings, which help the insects to either walk or fly. The abdomen houses the reproductive organs for mating and for laying eggs. Stored product beetles and moths go through the egg, larval, pupal, and adult stages (Figure 2). The life cycle of most stored product insects starts with eggs. Soon after mating, the female lays eggs in a suitable site where larvae hatching from the eggs have a chance of successfully finding the food source and establishing in it. Larvae hatching from the eggs (first instars) feed on food materials and gradually get bigger in size by shedding their skin several times (molting). The larva between molts is called an instar. The number of instars is generally fixed for each species. Many stored product insects go through 3-5 instars. The last instar or fully-grown larva turns into a resting stage called the pupa, where the larval tissues are being broken down to form adult tissues. Adults emerge from pupae, and the life cycle continues again. The shape of the eggs, larvae, pupae, and adults is different for different insect species. Some larvae may have legs while others may not. Characters of various life stages, especially those of adults, can be used to easily identify a given species. Some species require special techniques (clearing the specimens, examining size and distribution of body hair, or examining reproductive structures) for proper identification. Table 1 lists important stored product insects and salient characters used for identifying them. The USDA's Agriculture Handbook 500 (USDA 1980) on "Stored-Grain Insects" has beautiful color pictures of important stored product insects with notes on their biology.

Figure 1. Diagram of a generalized insect showing various body parts (Haines 1991).

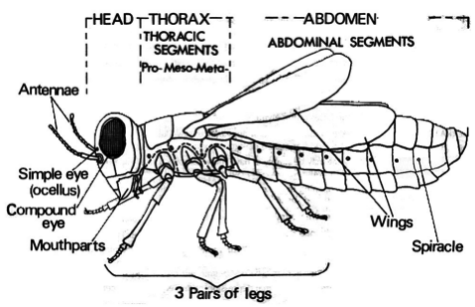
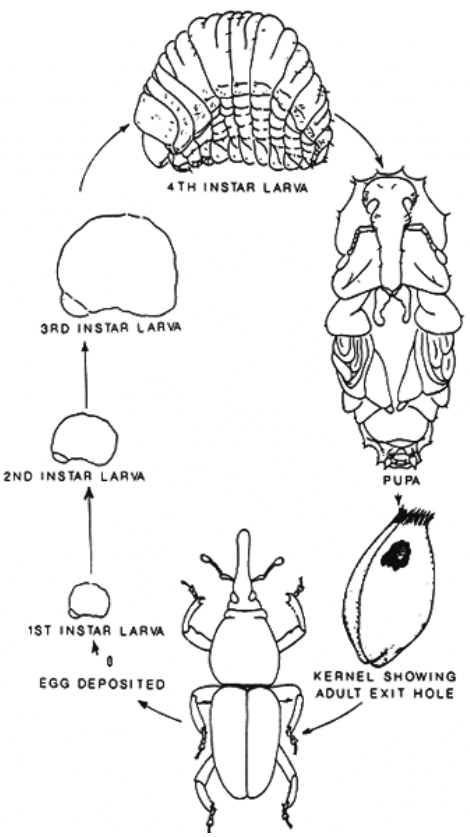


Figure 2. Stored-product beetles and moths go through the egg, larval, pupal, and adult stages. The figure shows rice, granary, or maize weevil life cycle.



Feeding Habits

Stored product insects can feed on a variety of food products. A few stored product insects feed exclusively on storage molds, and recognizing such species from those that cause damage is important, as the former do not damage stored products. Stored product insects can be grouped

Table 1. Features of important stored-product insects associated with feed manufacturing plants.

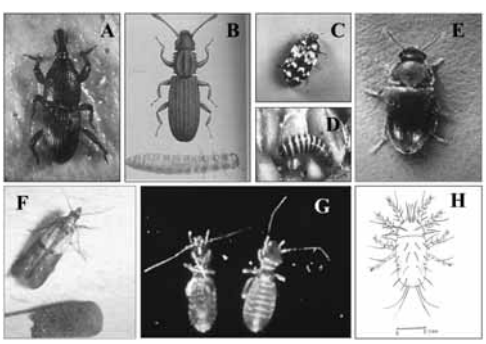
Common name	Scientific name	Body of adults			Identification features
		Shape	Size (inch)	Color	
			Internal feeders		
Angoumois grain moth	Sitotroga cerealella (Oliver)	Moth-like	0.20–0.28	Yellowish brown	Both pairs of wings are narrow; hind wings are pointed at the tip and have long fringe of hairs; labial palps are long, slender and sharply pointed.
Granary, maize, and rice weevil	Sitophilus granarius (L.), S. zeamais Motschulsky, and S. oryzae (L.)	Oval with long tip	0.09–0.18	Dark brown	Front head with snout; antennae elbowed and clubbed.
Lesser grain borer	Rhyzopertha dominica (F.)	Cylindrical	0.08–0.12	Brown	Head invisible when viewed from above; wings have rows of punctures; last 3 segments of antennae form loose clubs.
			External feeders		
Almond moth	Cadra (Ephestia) cautella (Walker)	Moth-like	0.28–0.39	Grayish brown with dark pattern	Wingspan 0.43 0.79 inches and wings have broadly rounded tips; the labial palps curve upwards in front of the head and blunt at the tip.
Cigarette beetle	Lasioderma serricorne (F.)	Oval	0.08–0.10	Light brown	Wing surface is smooth; antennae are saw-like (serrate).
Confused and red flour beetles	Tribolium confusum (J. du Val) and T. castaneum (Herbst)	Oblong	0.09–0.17	Red brown	Forewings with longitudinal lines: eyes divided by head margins; last segments of antennae form clubs.
Drugstore beetle	Stegobium paniceum (L.)	Oval	0.08–0.10	Light brown	Wings are slightly hairy with rows of punctures; last 3 segments of antennae form loose clubs.
Flat and rusty grain beetle	Cryptolestes pusillus (Schönherr) and C. ferrugineus (Stephens)	Oblong; flattened	0.06–0.08	Light brown	Small and flat; antennae are hair-like and sometime longer than body.
Foreign grain beetle	Ahasverus advena (Waltl)	Oblong; flattened	0.08–0.12	Red brown	Prothorax has blunt tooth at each front corner.
Indianmeal moth	Plodia interpunctella (Hübner)	Moth-like	0.28 0.39	Bicolor: 2/5 cream the rest dark-reddish brown	Wingspan 0.55 0.71 inches and labial palps (mouth parts) point directly forwards.
Khapra and warehouse beetle	Trogoderma granarium Everts and T. variabile Ballion	Oval	0.08–0.12	Brown	Hairy wings with irregular pale markings; a small eye between compound eyes; last 3–5 segments of antennae form clubs; cavities for resting antennae.
Merchant and saw-toothed grain beetle	Oryzaephilus mercator and O. surinamensis	Long, flat, slender	0.10–0.14	Dark brown	Antennae are short and clubbed; prothorax has 6 tooth-like projections along each side.
Psocids or booklice	Liposcelis bostrichophila, L. entomophila, and L. paeta	Flattened and slender	0.03–0.06	White, pale yellow to light brown	Soft body; wingless; long hair-like antennae; male is shorter than females except L. bostrichophila.

Sources: Baur (1984), Haines (1991), and Hedges and Lacey (1996).

into several categories based on their feeding habits or preferences. Commodity feeders are associated with cereal grains or grain products. These insects are further classified as internal and external feeders. Internal feeders include such species as the rice, granary, and maize weevils, lesser grain borer, and Angoumois grain moth. Female weevils after mating chew a shallow hole and lay eggs just below the kernel pericarp. The female plugs the hole with a gelatinous substance after laying an egg, which makes it difficult to separate infested and uninfested kernels by visual observation. Special stains are needed to detect egg plugs. The use of X-rays is used sometimes to detect stages of immature weevils inside grain kernels. Larvae hatching from eggs burrow further into the kernel and continue their development. Larval and pupal development occurs within the kernel, and the adult weevil emerges making a circular hole. In the case of lesser grain borer and Angoumois grain moth, eggs are laid outside the kernels, and larvae hatching from the eggs bore through a suitable fissure in the kernel pericarp. Larvae and pupae complete their development inside the kernels. Weevil larvae do not have legs as the eggs are laid inside kernels, whereas lesser grain borer and Angoumois grain moth larvae have three pairs of legs to facilitate movement so that larvae can find suitable kernels for boring.

External feeders include all other species whose eggs, larval, and pupal stages develop outside the kernels or food materials. These species include the rusty and flat grain beetles, red and confused flour beetles, and sawtoothed and merchant grain beetles, to name a few. Rusty and flat grain beetles consume the kernel germ, whereas the red and confused flour beetles and sawtoothed grain beetles require broken kernels or flour for survival and development. Fungus feeders consist of such insects as the hairy fungus beetle and foreign grain beetle. These species survive and develop on molds growing on stored commodities. Their presence is an indication of mold infection within stored commodities. Scavengers are insects that feed mainly on decaying organic matter of plant or animal origin. Some examples include the larder beetle, warehouse beetle, khapra beetle, and carpet beetle. Figure 3 gives examples of several stored product insects that fit the categories described above. It is important to realize that some species, such as the Indianmeal moth, in the absence of grain or grain products, can develop on pure cultures of storage molds. Predators, such as the minute warehouse pirate (anthocorid) bug, are beneficial insects. They feed on eggs or immature stages of pest insects. Parasites are minute beneficial wasps that lay eggs on or in life stages (eggs, larvae, or pupae) of pest insects. Discussion pertaining to predators and parasites is beyond the scope of this chapter. Excellent reviews by Brower et al. (1995) and Schöller and Flinn (2000) provide information on these natural enemies and their role in stored product pest management.

Figure 3. Examples of selected stored-product insects. A, granary weevil; B, sawtoothed grain beetle; C, dermestid adult; D, dermestid larva; E, hairy fungus beetle; F, Indianmeal moth; G, psocids or booklice; and H, grain mite.



Notes On Biology And Ecology

Insect biology deals with number of eggs laid by females (fecundity), egg viability; larval, pupal, and adult survival; development of various life stages; and longevity of adult males and females. Ecology refers to the environment surrounding stored products, such as temperature, humidity (stored product moisture), dockage, and nutritional quality of the food. These ecological factors have a tremendous influence on the biological performance of insects. The body temperature of stored product insects varies with that of the ambient, or in other words, insects are cold-blooded. Insects have a lower temperature threshold at or below which development ceases. Across all species, this threshold is generally between 60 and 70°F. Development is fastest at optimal temperatures (ranging from 80-95oF, depending on the species). At temperatures above the optimum, insect development is affected and survival is greatly reduced. At 113-120oF insects die within a day, at 122-140°F they die within an hour, and above 144°F they die within a minute. Therefore, extremely cold and high temperatures can be used for insect management. The development of eggs and pupae is independent of humidity,

but the development of larvae is faster at higher than at lower humidity levels. Table 2 shows the predicted egg-to-adult developmental times of economically important stored product insects at different temperatures. The number of eggs laid by insects varies from 200-400 per female. In the case of beetles, eggs (0.2-3 per day) are laid throughout the adult life, whereas in the moths, most of the eggs are laid within 2-4 days after emergence from pupae because moths live for about 1-2 weeks. The number of eggs laid also is a function of temperature. More eggs are eggs laid at optimum temperatures than at cooler temperatures. Exposure of pupae to high temperatures (above the optimum), in some species, can lead to sterility in adults. In the Indianmeal moth, eggs are prematurely released if unmated or mated female moths are exposed to any stress such as carbon dioxide gas or dichlorvos (DDVP) fog.

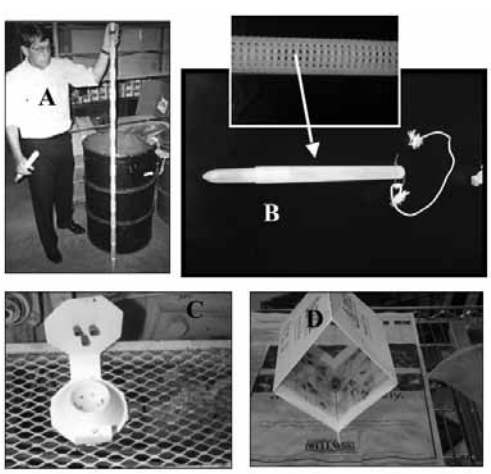
Table 2. Egg-to-adult development in days of important stored-product beetles and moths at different temperatures.

Species	Temperature								
°F	63.5	68.0	72.5	77.0	81.5	86.0	90.5	95.0	99.5
°C	17.5	20.0	22.5	25.0	27.5	30.0	32.5	35.0	37.5
Moths									
Cadra cautella	108.9	76.7	57.1	45.3	38.3	34.4	32.5	31.8	__a
Plodia interpunctella	150.9	99.3	67.3	48.1	37.9	34.9	38.4	49.1	__
Beetles									
Cryptolestes ferrugineus	__	__	53.4	37.0	28.1	23.2	20.6	19.0	18.2
Cryptolestes pusillus	__	__	53.1	45.1	38.5	32.9	28.4	25.1	24.5
Oryzaephilus surinamensis	__	__	48.5	36.4	27.9	22.4	19.8	20.8	27.0
Sitophilus oryzae	__	52.9	43.2	35.9	30.6	27.4	26.7	29.1	36.7
Tribolium castaneum	__	__	__	41.8	32.7	28.4	26.3	23.4	21.7
Tribolium confusum	__	__	56.2	44.6	35.6	28.5	23.0	20.0	34.1
Rhyzopertha dominica	__	__	__	58.8	49.9	42.4	36.1	31.0	__
Lasioderma serricorne	__	94.8	62.1	43.1	32.9	28.3	27.9	30.7	36.5
Stegobium paniceum	153.5	105.4	73.4	52.9	41.9	41.6	58.4	__	__

Source: Hagstrum et al. (1995).
aData not available.

Most stored product insects are capable of flight. However, species such as the granary weevil and confused flour beetle are incapable of flight, and sawtoothed grain beetle has not been observed flying. Consideration of an insect's oviposition and flight behaviors is important for their management. For example, weevils lay eggs inside the kernels. Therefore, controlling adults before they had a chance to mate and lay eggs would be an effective pest management strategy. Furthermore, fumigation is recommended for killing eggs and other immature stages developing inside the kernels. In the case of lesser grain borer and Angoumois grain moth, newly hatched larvae burrow into the kernels. Therefore, the use of grain protectants would be effective in killing larvae hatching from the eggs. In the case of confused flour beetle and granary weevil, grain movement spreads infestations, because the adults are incapable of flight. Therefore, infestations of these two species would be restricted to a particular bin or silo, or a food product. Furthermore, management tactics such as fumigation would be very effective because adults are unable to escape by flight.

Figure 4. Insect sampling tools. A, grain trier; B, perforated probe trap, with the inset showing perforated trap body; C, food-baited trap with a shallow receptacle for oil, and cover fitted with three different pheromone lures; and D, pheromone-baited sticky trap for moths.



Detecting And Monitoring Insect Populations

Sampling is an integral component of pest management. Several devices are available for sampling stored product insects (Figure 4). These devices are valuable in detecting or estimating insect populations. Without sampling, pest management measures may be applied unnecessarily or they may not be applied when necessary. The former would result in frequent use of preventive measures, and may minimize product damage or loss. However, the latter would be very costly, because pest management would be applied after significant damage has occurred. The use of sampling information minimizes these risks, and allows use of pest management tactics

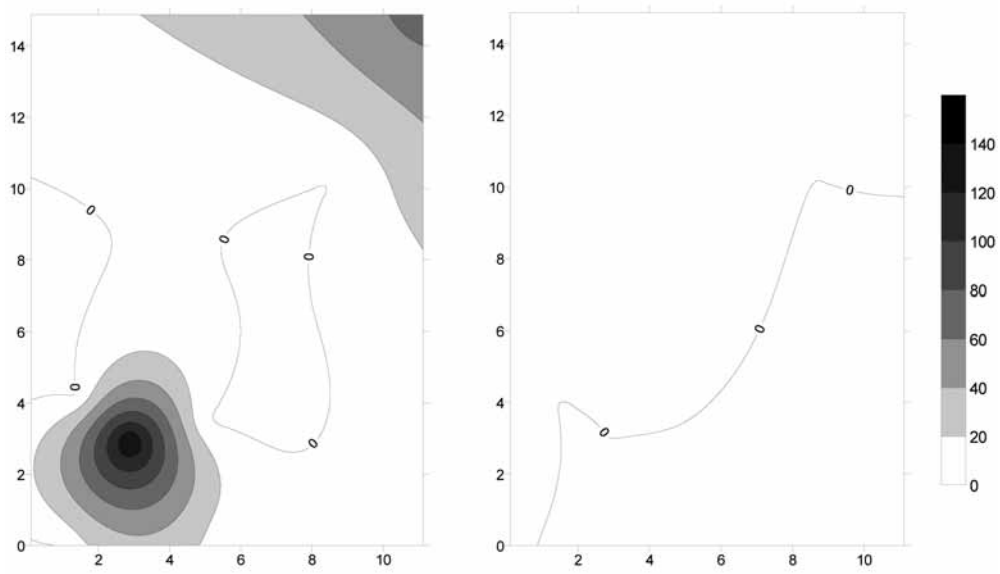
only when needed. Therefore, development of a customized pest management program for individual manufacturing plants requires generating sampling information over several years to detect trends in insect distribution and abundance with respect to various operations within the plant. Subramanyam and Hagstrum (1995b) described, in detail, the data and analyses needed to develop sampling plans for stored product insect detection, estimation, and pest management.

Stored product insects can be estimated using absolute or relative estimates. Absolute estimates are obtained by counting insects in a known amount of grain or product. These estimates are important for making pest management decisions, because the exact number of insects in grain or product is known. These numbers also could be related to product weight, quality loss, or consumer complaints. Grain or grain products can be sampled with devices such as the grain trier, deep bin cup probe, spear sampler, vacuum probe, Pelican sampler, and Ellis cup. Insects in bulk-stored grain, bagged grain, or bagged feed products can be sampled by removing a certain number of samples (of grain, product, or bags). These samples are examined for live insects. For reliable estimates, it is important to take a large number of samples (> 30 samples). Insects are generally separated from grain or products using a set of sieves. Generating absolute estimates is time consuming, labor intensive, and expensive. Relative estimates are obtained by using various types of traps that exploit insect behavior. Traps are generally used with food or pheromone baits (lures). Food-baited traps are used for sampling crawling beetles (e.g., red flour beetle), and pheromone-baited traps are used for flying moths (e.g., Indian meal moth) or beetles (e.g., cigarette beetle). The food-baited traps are attractive to several species of stored product insect adults and larvae. Unlike food-baited traps, the sex pheromone (released by females that attract only males) or aggregation pheromone (released by males that attract both sexes) baited traps are species-specific. Furthermore, sex pheromone traps are highly attractive and more effective than food-baited traps in capturing insects, or in other words, they have a higher trap catch efficiency. Perforated probe traps can be used for sampling live insects in bulk-stored grain or pelleted feed (Figure 4B). Insects randomly moving within the grain mass are captured in the trap vial.

To overcome manual counting of insects in probe traps, an Electronic Grain Probe Insect Counter (EGPIC) has been developed (Shuman et al. 1996), which counts insects electronically. EGPIC probes have the same tubular trap body, plus an electronic counting device It gives time-stamped data of insect counts, and commercial models for use in bins and silos are currently being developed. These units do not provide precise estimates of actual insect counts (Arbogast et al. 2000), and the commercial models being developed may rectify this limitation. Food- and pheromone-baited traps (Figures 4C and D) can be used for sampling insects in feed manufacturing plants. Food-baited traps can be used with pheromone lures to enhance trap catch (Phillips et al. 2000). These traps are generally placed on the floor, whereas pheromone-baited traps are hung above the floor (> 5 feet). Grain oil mixtures or cracked grains and/or cracked carobs are used as food baits (Subramanyam 1992). Cracked grains or carob baits can be enclosed in wire or nylon mesh envelopes, and these envelopes can be placed in different areas of the plant. However, the size of the mesh openings should be large enough to allow insect entry and small enough to prevent the bait from sifting out.

Devices that provide absolute estimates take an instantaneous sample (in time and space), whereas traps can be used for varying time periods. They can sample insects 24 hours a day, 7 days a week. Therefore, traps are able to detect infestations early, enabling pest management measures to be instituted at the right time to prevent infestations from reaching unacceptable levels. It is important to realize that absence of insects in traps does not indicate that insects are not present in the area being sampled. Insect mobility and a dust-free environment are essential for traps to work efficiently. Insect mobility is influenced by factors such as insect age, stage, sex, temperature, humidity, crowding, and accessibility and suitability of food. Traps should not be used at cooler temperatures (< 65°F), because reduced insect activity. Conversely, at warmer temperatures, increased insect activity results in greater insect numbers being captured in traps. During warm weather, traps should be checked frequently to prevent trap saturation, which makes them less efficient in additional insects. Accumulation of dust also decreases trap efficiency, because the available surface area for additional insect capture is reduced. The food and pheromone baits last 4-6 weeks, and should be replaced at monthly intervals. The biggest challenge has been to relate trap catches (relative estimates) to insects in grain,

Figure 5. Contour maps showing distribution of beetle trap catches in the first floor of the Kansas State University pilot feed mill before (left) and after (right) a heat treatment. The x and y axes scales are expressed in meters. Expressing axes scales in feet will not affect the distribution of trap catches shown.



grain products, or specific areas of a feed manufacturing plant (absolute estimates). Presently, such information is limited. Despite these limitations, traps can still be used in feed manufacturing plants, because sampling information can be obtained easily and quickly.

How can traps be used in a feed manufacturing plant? Both the food- and pheromone-baited traps should be spread in a loosely arranged grid pattern throughout the plant, and insects captured in them identified to species and counted. More than 30 traps should be used per 5,000 square feet of surface. This information is based on our insect sampling in pilot flour and feed mills, and retail pet stores. Software programs such as Surfer (Keckler 1995) can then be used to generate contour (spatial) maps to identify areas of high and low infestations (Figure 5). These contour maps enable the plant manager or pest management professional to concentrate on pest management efforts in areas where infestations are severe. This precision targeting of management efforts may have the greatest impact on pest populations. It is also economical, because pesticides or alternatives are used only in specific areas of the plant. In addition, a thorough visual examination of infested areas may indicate reasons for high numbers of insects, such as a torn bag, spilled product, or infestation in machinery. The use of contour maps before and after a pest management intervention can be used to gauge the degree and duration of pest suppression. Figure 5 shows changes in beetle numbers in one of the feed mill floors at Kansas State University before and after a heat treatment. In addition, generating contour maps following an intervention helps in identifying areas where incipient infestations are beginning to emerge within the plant.

Stored Product Mites

Like insects, stored product mites (Figure 3H) are commonly associated with grain and grain products. They reduce nutritive value of infested products, and can cause allergic responses in animals consuming infested products. Some sensitive individuals handling infested product may also show allergic responses. Stored product mites are very small and translucent. Therefore, their infestations are commonly overlooked until they become severe. Unlike insects, adult mites have four pair of legs, and lack wings and antennae. Stored product mites are commonly soft-bodied, slow moving and pale in color. Eggs laid by mites go through a six-legged larval stage, followed by several nymphal stages (protonymph and tritonymph), and an adult stage. Under adverse conditions, some species of mites undergo a resistant resting stage (after the protonymph stage) called hypopus. The hypopus stage serves as a means of dispersal or survival in periods of nutritional or environmental stress.

Like insects, mite populations are regulated by temperature, relative humidity, and food. Temperature range for development is typically 37-65°F, and they thrive well at >85% relative humidity. Grain infesting mites prefer the nutritious germ, but they may also consume the endosperm, if it is moldy. Under optimum conditions, mite development is completed within 2-3 weeks, and the numbers may increase over 1000-fold within that period.

The grain or flour mite, Acarus siro Linnaeus, is the most important pest species in temperate stores. It infests grain and grain products, medicinal herbs, hay, and cheese. The egg-to-adult developmental time ranges from 9 days at 82°F and 80% relative humidity to 78 days at 39°F. Average egg production is 230 eggs per female. Under favorable conditions (68°F and 80% relative humidity), each female may lay up to 670 eggs. Other species such as the brown flour mite, Gohieria sp.; house mite, Glycyphagus domesticus, and American house mite, Dermatophagoides farinae, may be found in feed manufacturing plants. Recognizing mite species is a specialized skill and requires a high powered microscope.

Reducing the ambient relative humidity, and reducing grain/product moisture content are two techniques that can reduce mite infestations. Organophosphate pesticides and commercial diatomaceous earth dusts can be applied to grain to manage mites (Cook and Armitage 1999).

Vertebrate Pests

Rats And Mice

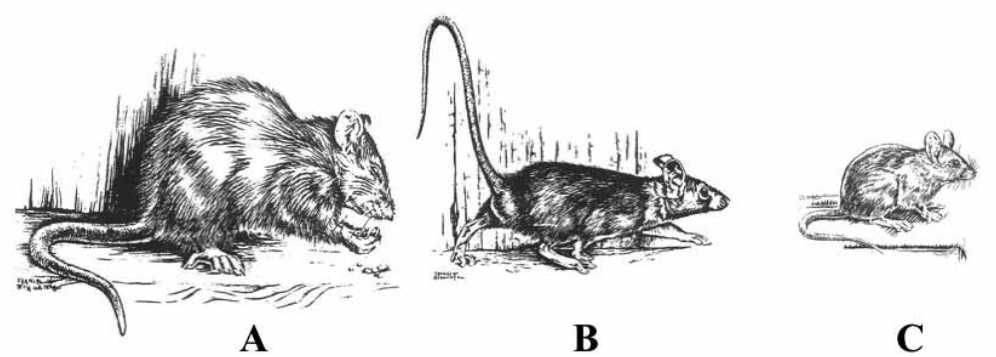
Rats and mice often enter feed manufacturing plants in search of food and harborage. The availability of highly nutritious food in feed manufacturing plants makes it attractive for rodents. More damage is caused by contamination than by actual feeding. Rodents can contaminate feed material by their droppings, urine, and hair. They are also known to transmit many diseases, such as plague, murine typhus, and leptospirosis.

Rodents are well adapted to human habitats. There are more than 1,700 species of rodents, but only a few are considered pests. These include the Norway rat (Rattus norvegicus), roof rat (Rattus rattus), and house mouse (Mus musculus).

The Norway Rat

The Norway rat, also called “brown rat” or “sewer rat”, is usually brown or grayish brown above, and light colored underneath (Figure 6A). An adult measures 12-18 inches from its nose to the tip of its outstretched tail, and may weigh just over a pound. Its tail is semi-naked and conspicuously ringed. It has a blunt nose and close-set ears. It is possible to distinguish a juvenile rat from a house mouse by the fact that the young rat has feet that look too big for its body. It also has a head that is disproportionately large.

Figure 6. Diagrams of Norway rat (A), roof rat (B), and house mouse (C). Not drawn to scale.



Female rats are usually ready to mate when they are 3-4 months old. After a gestation period of about 23 days, a female rat will have an average of 8-10 pups in a litter, although she can have as few as 2 and as many as 22. If there is plenty of food, water and shelter, her litters will be larger. If food, water or shelter is in short supply, her litters will be smaller. Newborn rats are naked and blind. They nurse from their mother for about a month. The mother rat can breed again before her young leave the nest, so under ideal conditions, she can have a litter every other month.

In the wild, rats typically live about a year. They live in dumps, dumpsters, sewers, and on ships. However, they prefer to live in burrows in the ground. In heavy infestations, rats may be found in many locations at or above the ground level. The dominant (alpha) males generally prefer ground burrows. Often, these burrows are around the perimeter of a building where food supply is abundant. They travel 100 feet or more from their burrow to the food and water sources. When food becomes scarce, or the population gets too large, rats will travel over land for 5-6 miles looking for a new home.

Rats live in colonies, with a large number nesting in one area and sharing food and water sources. However, they have a clear "pecking order." The biggest and strongest (alpha) males live in the choicest burrows, and have first priority of food, water, and females. Lower-order rats learn to stay out of the way of those enjoying higher social status. A strange male rat coming into a colony will be attacked, and either driven off or killed by the dominant males.

Norway rats will eat nearly anything, but tend to prefer meats, grain, grain products, eggs, and fruits. Daily food consumption is about an ounce. They are most active at dusk and like to feed at night. They require a daily source of drinking water.

Rats see poorly and are color blind. They have a keen sense of smell, which helps them find food and obtain important information about other rats, especially concerning the other rats' sex, mating readiness, or social status. Their sense of taste is excellent, and they can detect small quantities of foreign substances, such as rodenticides in their diets. Rats also have excellent hearing. Their whiskers are sensitive to touch, and the guard hairs on their body guide them along walls in total darkness. They have a good sense of balance.

Norway rats have the following physical abilities, which make them successful pests and difficult to manage. They can squeeze through any opening bigger than 1/2 inch square, climb the outside of vertical pipes and conduits up to 3 inches in diameter, climb the outside of a vertical pipe of any size if the pipe is within 3 inches of a wall or other continuous support, crawl horizontally on any pipe or even a wire, jump up as high as 36 inches from a flat surface, execute a 48 inches broad jump on a flat surface, climb brick or other rough walls, swim 1/2 mile through open water, and dive more than a foot down for food or to get into a plumbing line.

Rats are quick learners. They quickly learn to avoid a particular food (or toxic bait) that makes them sick. This behavior is called bait shyness. Rats also can learn to avoid traps or other hazards. Rats like to do things the same way every day, going over the same trails, to eat the same food, and drink the same water. They are very suspicious of anything new or different. Rats are neophobic, and avoid anything new for several days. At first, they might avoid a new food altogether. A few days later, they may sample it. If everything seems all right that night and the rats do not get sick, they may accept the food.

Roof Rat

Roof rat, also known as black rat, ship rat, gray-bellied rat, Alexandrine rat, and white-bellied rat, is smaller and slender than the Norway rat. The adults weigh about 5-9 ounces. Their fur is grayish black to solid black, and fur on the underside of the body varies from buff white to gray. The snout is pointed and not blunt, like the snout of the Norway rat (Figure 6B). The ears are large and the tail is long enough to reach the snout when pulled back over the body (do not attempt this with a live specimen!). The life cycle of roof rats is very similar to that of Norway rats, except that their breeding is somewhat less prolific.

Roof rats are not well adapted to cool climates. They are found in the coastal and more tropical regions of North America. In the U.S., they are found in coastal areas of Washington State, Oregon, California, along the Gulf of Mexico, and in Atlantic coast states from Texas to Maryland.

Many of the general behavior traits listed for Norway rats also apply to roof rats.

Roof rats commonly live above the ground. In warmer climates they often build tree nests, as squirrels do. They readily enter attics and other above ground harborages. Management strategies should therefore take this arboreal nature into account. For example, traps or baits should be placed in above ground locations.

House Mouse

The house mouse is dusky gray and about 3 1/2 inches long. Its tail is semi-naked and scaly, and nearly as long as the body. The feet are small in proportion to its body. The eyes are also relatively small (Figure 6C). House mice weigh only between 1/2 and one ounce when fully grown. Newborn mice (pups) are hairless, blind, and extremely small.

Female house mice are ready to mate when they are little over a month old. The time from onset of pregnancy to birth of the litter (gestation period) is 19 days, or under three weeks. Each litter may contain 5-6 young mice. One female mouse can have up to 8 litters in a year, and produce a total of over 40 new mice! When food is scarce or under crowded conditions, a female will have fewer litters per year, and fewer pups per litter. House mice live nearly a year.

Because of the constant mobility of mice and the fact that they urinate and defecate “on the run”, and sample food from many different items, the potential exists for mice to transfer Salmonella bacteria and numerous other disease-causing organisms from infected surfaces and materials to human or animal food. Perhaps more importantly, mice have recently been identified as a cause of childhood asthma in inner-city neighborhoods, where mice and their allergens are present in a high percentage of homes.

House mice see poorly and are color blind. However, all of their other senses are very sharp. They have a good sense of smell, taste, and an excellent sense of balance. They have acute hearing, which enables them to detect and escape danger. The whiskers near their nose and the guard hairs on their body are very sensitive to touch. Some physical abilities of mice include the ability to jump 12 inches onto a shelf or ledge from ground level. They can broad-jump 2 feet from a running start, which explains how they can sometimes leap across a snap trap or glue board. They can climb up almost any vertical surface, if the surface texture is rough. They can run up bricks, pipes, wire mesh and weathered sheet metal. However, they cannot climb glass and smooth sheet metal, or other smooth surfaces. Mice can easily run along small ropes, electrical wires, squeeze through any crack more than 1/4 inch (juvenile mouse) to 3/8 inch wide (adult mouse), and drop from a height of 8 feet to the floor without injury. Unlike rats, mice are not good swimmers.

Damage by mice is often caused by their habit of collecting soft materials for nest lining. Burlap feed and seed sacks are a favorite. Other nesting materials include paper and furniture upholstery. Favorite nesting places include hollow walls, ceiling spaces, under or behind cabinets, underneath stoves and refrigerators, and similar enclosed spaces. Voids in or between stored materials, particularly sacked feed, are favorite nesting sites for mice.

Mice prefer to eat small amounts of various foods at frequent intervals, and thus a mouse can cause a lot of damage. For example, one mouse in a pallet of sacked feed can contaminate the whole lot by chewing into all of the sacks. Mice are nocturnal animals, and are most active at dusk. They prefer grain products, especially cereals and seeds, but they also like peanuts and peanut butter, dog food, pineapple juice, flour, and many other foods. They eat many times in a single night, traveling constantly between their nest and food sources. A mouse, on average, can consume 0.1 ounce of food in one night. Mice can obtain water from the food they consume. However, if water is available, they will drink it.

Weeds, tall grass, low bushes, equipment, or junk stored on the ground provide harborage for mice. Mice are attracted to odors of food, garbage, and feed coming from a building. Warm exterior walls in fall and winter attract mice to such buildings. When mice first enter a building, they may travel widely to inspect their new home. After mice are established in a building, they prefer to travel as little as possible, and may live and forage within a 10 feet radius. If food is hard to find, they may travel hundreds of feet in search of food. Travel is limited or restricted if there are many mice in the area. This occurs because male mice stake out a territory and attack other males entering their territory.

Signs of Rodent Activity

Rat Burrows. These are about 3 inches in diameter. The grass is usually worn down around them, and there may be fresh dirt thrown out. Norway rat burrows are normally fairly shallow, about 18 inches down, but may be complex with several interconnecting passageways.

Trails and tracks. Rodents use the same path during their foraging activities. Inside a feed manufacturing plant, trails may be found in the grain dust. Rodent tracks are easy to see in grain dust or flour. Rodent activity can be verified by dusting an area with flour and checking it for tracks within a day or two.

Droppings. Rodent droppings are black and solid; fresh droppings are hard and dull. Norway rat droppings are 1/2 – 3/4 inch long, and blunt at both ends. Roof rat droppings are spindle-shaped, whereas Norway rat droppings are capsule-shaped. Mouse droppings are pointed, and much smaller than rat droppings. They are only about 1/8- 1/4 inch long and pointed at one end. One mouse can produce up to 50 pellets per day! Droppings may be found along runways, but are more frequently found where they stop to eat.

Urine stains. Characteristic odors from rodent urine and body glands can be noticed during large infestations.

Rub marks. Dirt and oil from rodent bodies will make grease marks on walls and other surfaces in their runways. Rub marks may also be seen around burrow openings, in walls, on floors or ceilings, or around bottoms of joists where rodents have been traveling along beams or sill plates.

Gnaw marks. Rodents like to gnaw on things. The marks of their teeth on woodwork, electrical wiring, food packages or the food items themselves are a sign of rodent infestation.

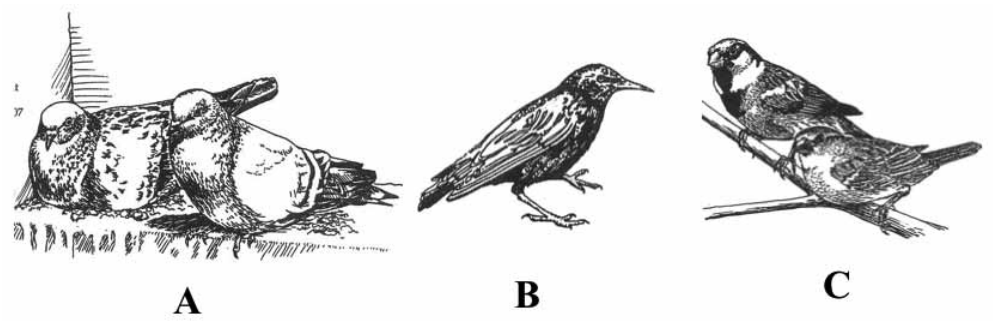
Birds

Most people consider birds as desirable components of our environment. Many bird species are protected by federal and state wildlife laws or by local ordinances. But there are some birds that cause problems in and around buildings, mainly due to their noise, droppings, and nesting habits. In addition to consumption and contamination of grain and grain products, birds also spread certain animal and human diseases. Some stored product insects such as dermestids are associated with bird nests. They feed on bird feathers and dried carcasses. Birds act as hosts for various ectoparasites such as ticks, fleas, and mites. Like rodents, many birds have adapted well to human environments. The shelter provided by many buildings for nesting and roosting, and adequate food and water, attracts birds to these sites.

Many birds have a potential for becoming pests. The common bird pests are pigeons, starlings, and house sparrows (Figure 7A-C). These three species are not protected by the Migratory Bird Treaty Act of 1918, but may be protected by state and local ordinances. Other non-pest birds that are protected by federal laws include gulls, woodpeckers, and barn swallows. In the U.S., these birds may only be killed after other methods have failed, and after a permit has been obtained from the U.S. Fish & Wildlife Service.

Pigeons are serious bird pests found in both city and rural areas. They tend to congregate in flocks of several hundreds. They inhabit roofs, ledges, attics, eaves, and any part of the building that permits

Figure 7. Important bird pests. Pigeons (A), European starlings (B), and house sparrows (C). Not drawn to scale.



nesting. They primarily feed on seeds and grain. The house or English sparrows are small, stocky birds that live in loose flocks and nest in building eaves, vents, or other openings. Although they feed on a variety of items like fruits and leaf buds, their preferred food is grain. Their activities are restricted to a one-mile radius. Starlings are also pests in both city and rural areas. They are gregarious and form large communal roosts from late summer to spring. Since they number in several thousands, they can consume large quantities of food. They feed on a variety of food materials ranging from fruits, seeds and food scraps. Insects form a major part of their diet.

Integrated Pest Management

The use of sampling information, assessment of cost/benefit and risk/benefit ratios, and judicious use of pesticides and alternatives for managing pests is called integrated pest management (IPM). The goal of IPM is not to eliminate pests, but to maintain them below damaging levels. Also, IPM approaches rely on using pesticides only when needed, which has beneficial effects such as delaying development of pesticide resistance and extending the useful life of pesticides. The following discussion provides IPM guidelines for insects, rodents, and birds associated with feed manufacturing plants.

Insects

The best approach for managing stored product insects from causing aesthetic or economic loss is to use various preventive techniques. Pesticides should be used as a last resort. IPM methods range from in-plant and equipment sanitation to inspection, use of traps, and application of pesticides and alternatives. The first step in insect management is identifying the insect species, and understanding its biology, ecology, and behavior. Improper identification may result in failure to intervene or may result in using inappropriate management measures that are destined to fail.

Insects enter feed manufacturing plants through open doors and windows. Entryways into the plants should be closed. However, this is not always possible. The use of air curtains above open doors prevents insect entry by creating positive pressure airflow near the doors. The use of plastic strips may also minimize insect entry. Broken windows should be screened with mesh screens, and damaged mesh screens should be replaced with new ones. Bulk-stored grain should be inspected at the time of receipt and after storage at monthly intervals for signs and presence of insects. Measurement of grain temperatures within silos and round metal bins provides an indirect measure of insect activity, because insects can cause dry grain heating resulting in temperature increases of 108°F. Bulk-stored grain or pelleted feed in silos or bins should be sampled with vacuum probe, grain trier, or deep bin cup probe to estimate absolute insect densities. Perforated probe traps also can be used in such bulk-stored grain or pelleted feed. The traps should be checked weekly during warm weather conditions. Pheromone-baited traps should be placed above the grain for detecting and monitoring moth infestations, which are typically confined to the upper layers of the grain mass.

Incoming ingredients should be inspected, including the trailer that delivered the material. Grains that are received at the plant should be inspected to determine whether they are infested. If live insects are present, the grain should be fumigated with phosphine to kill all species and stages of insects

Figure 8. In commercial facilities grain is fumigated by placing phosphine pellets in a pellet dispenser (A). Grain can be treated with a protectant as it is being augered into a bin (A).

(Figure 8A). If grain is to be stored for several months during warm weather, treatment with a grain protectant might be desirable (Figure 8B). However, under the 1996 Food Quality Protection Act, the existing organophosphate grain protectants (malathion, chlorpyrifos-methyl, and pirimiphos-methyl) may be cancelled or severely restricted, and their future remains uncertain.

Bagged materials should be sampled with spear samplers or scoops and the contents sifted to determine infestations. The seams of bags should be carefully inspected for insects or webbing caused by moth larvae. The dump pits and horizontal screw conveyers should be inspected for insect activity, and should be cleaned regularly to remove grain residues.

Sanitation, both outside and inside silos, bins, and feed manufacturing plants (including floors and equipment), is the most important IPM technique (Figure 9A,B). The grounds and plant perimeter should be devoid of any vegetation and food product spills, and should be paved. This eliminates harborages and creates an unfavorable environment for pests. The roof should be inspected regularly

Figure 9. Sanitation outside (A) and inside (B) grain storage facilities is important for creating unfavorable conditions for pest survival and reproduction. Accumulated food residues, for example, in roll stands (C) can support insect infestations. The use of surface sprays (D) is important following sanitation to manage insects in feed manufacturing plants.

for proper drainage and for any accumulations of product, which may have leaked from bucket elevators, cyclones, exhausts, or other equipment positioned on, or passing through, the plant roof. Leaking equipment should be repaired and product accumulations removed. Storage facilities receiving grain should be thoroughly cleaned and treated with an approved pesticide to control residual insect populations to prevent contamination of insect-free grain loaded into the facility. Several diatomaceous earth formulations or cyfluthrin (Tempo) are recommended for treatment of empty storage facilities.

Silos and bins equipped with fans should use aeration for cooling grain (<60°F) to a point where insect activity or growth is suppressed below damaging levels (Reed and Arthur 2000). Other methods for grain cooling include chilled aeration (Burks et al. 2000).

The receiving and handling of grains and other ingredients in bulk can be a very dusty operation. It is virtually mandatory to have an effective dust control system on the receiving and handling systems. Proper dust control prevents dust from becoming a housekeeping problem, and reduces cleaning costs. Even with a good dust control system, some spillage will occur. Therefore, regularly scheduled cleaning is important in the receiving, handling, and storage areas. The Occupational Safety and Health Administration (OSHA) requires grain handling facilities to "develop and implement a written housekeeping program that establishes the frequency and method(s) determined best to reduce accumulations of fugitive grain dust on ledges, floors, equipment, and other exposed surfaces." Priority housekeeping areas where dust explosions are more likely to occur are also defined. Cleaning frequency should be based on the observed need, and may vary depending on the intensity of operations. As a general rule of thumb, walls, overhead areas, and equipment interiors should be cleaned at least once each month to prevent insect development. Dead spots in handling equipment can become breeding areas for insects unless they are cleaned monthly to break the insect developmental cycle. Floors may require daily cleaning to maintain an aesthetically clean work environment.

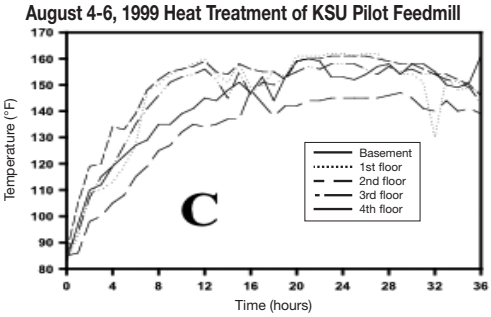
Regular inspections will enable management to determine the general status of plant sanitation. Inspections should be designed to identify potential or recurring problem areas. Emphasis should be placed on inspection of the interiors of equipment where "dead spots" allow product to accumulate. Regular and master cleaning schedules are important in processing areas of the plant. Floors in an active processing area should be cleaned daily. Interiors of processing equipment and systems should be cleaned, at least monthly, to prevent the build up of insects in dead stock (Figure 9C). Particular care should be given to identifying hidden areas in the plant that may house subfloor conveyors, bucket elevators, etc., because insect infestations in these areas may often go undetected until they become unmanageable.

The use of both food- and pheromone-baited traps is essential. The use of contour maps, coupled with visual inspections in problem areas, indicates reasons for the infestations and helps target sanitation and pest management measures.

Increased emphasis on cleaning and the use of insecticide sprays, fogs and/or mists in plant spaces has been used to supplement general fumigations as an alternative to spot fumigations. There are several pesticides that can be used inside a plant for spot, crack or crevice, or for general surface treatments (Figure 9D). Sanitation enhances effectiveness of these pesticides. General fumigation (with methyl bromide) requires proper sealing of the entire plant structure so that the toxic gas vapors can be held at lethal concentrations to provide effective insect kill. Sulfuryl fluoride is a potential alternative to methyl bromide, and is currently being tested for fumigation of food and feed manufacturing plants. It is presently not registered for use in food and feed plants. General fumigations are costly and time consuming, but may be required more frequently than in the past, where spot fumigations were employed. An effective alternative to fumigation is the use of heat treatment for disinfestation of the entire plant or specific plant areas (Figure 10). Heat treatments are gaining popularity because of the impending phaseout of methyl bromide by the year 2005. Gas, electric, or steam heaters can be used to supply the necessary heat (Figure 10A, B). During heat treatment, the temperature of

the feed manufacturing plant should be raised to at least 122oF and held at this temperature for 24-36 hours (Figure 10C). A successful heat treatment is one in which uniform temperatures of 122oF are attained in all parts of the plant, including equipment. This is usually accomplished by proper distribution of heat using strategically placed fans. Furthermore, sanitation and removal of grain and grain products from the plant enhances heat treatment effectiveness, because grain and grain products are poor conductors of heat. Insects in such insulated material could reinfest the plant following a heat treatment. In Canada, plant freeze-outs are used. The use of extreme temperatures (cold or hot) requires special preparation of the plant to prevent structural and/or equipment damage (see Mills and Pedersen 1990).

Figure 10. Feed manufacturing plants can be heated using natural gas heaters (A) with ductwork from the heaters extending into various floors of the plant (B). Temperatures obtained during heat treatment of the Kansas State University pilot feed mill (C).



The ease and effectiveness of maintaining a sanitation and pest management program in a feed plant is dependent, to a certain extent, on the design and construction of the plant and the equipment in use. Construction designs and materials can either enhance or complicate sanitation and pest management efforts. Concrete construction is better than wood from the standpoint of cleaning ease. Concrete can be made smooth, but wood construction has cracks and voids that can accumulate product, which is virtually impossible to remove and/or disinfest. Hollow walls, false ceilings, and other void areas in plant construction create harborages for pests and, quite often, are inaccessible for proper cleaning (Imholte and Imholte-Tauscher 1999). Equipment should be at least 18 inches from walls and ceilings to allow adequate space for cleaning. Although equipment maintenance is not a direct function of a sanitation/pest management program, it can play an important role in the quality of the program. Product that leaks from equipment in need of repair adds to the cleaning effort required to maintain the proper level of housekeeping. In addition, product that is recovered from leaks and spills may have to be discarded or diverted to a less valuable use.

Finished feed products may be stored and transported in bulk or bags. Bulk storage is commonly used for finished feed products prior to bulk load-out or packaging for bag shipment. Particular care needs to be exercised to assure that these products are not infested or contaminated in storage. Encrusting of material or mold build-up in bins is an indication of condensation or of a high humidity problem in the bin. This problem may be corrected by increased suction on the bin to carry off warm, moist air. Physical cleaning of the bin usually requires lowering properly protected workers into the bin to scrape down bin top and wall areas. If packaged materials are to be warehoused, they should be neatly stacked on pallets and stored in organized units at least 18 inches from walls and upright supports. This arrangement provides minimum space for cleaning along wall areas, facilitates inspection and inventory of the warehoused material, and allows for the placement, maintenance, and inspection of traps.

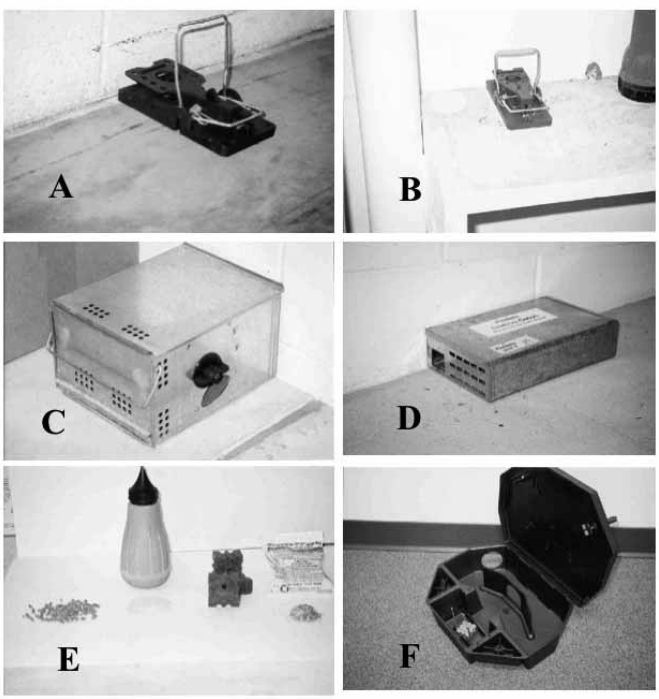
Packaged feed products should be shipped in clean transport vehicles. The manufacturer has a responsibility to his or her customers to inspect the transport vehicles for evidence of insects, rodents, chemicals, or other foreign materials, which might cause the products to become infested or contaminated in transit. Bulk transport vehicles should be inspected before loading. If the manufacturer maintains a fleet of bulk trucks or rail cars, a regular cleaning schedule should be established for them.

Rodents

Effective rodent management requires the use of several techniques. The key is to first hire a pest management professional, who can conduct a thorough inspection of your facility to determine the best strategy. Exclusion techniques or rodent proofing the building is the key to a successful rodent management program. Although total exclusion might not be possible due to the size or design of a facility, every effort must be directed to identify possible route whereby rodents can enter the building. Openings greater than 1/4 inch for mouse and 1/2 inch for rats must be sealed. Hardware cloth, coarse steel wool, or mortar can be used for sealing purposes. A 12-inch metal plate should be attached to the outside of doors. Rodents should be prevented from climbing pipes outside the buildings by fitting metal guards around the pipes. The ultimate aim is to exclude rodents from entering the facility.

All animals need food, shelter and harborage to survive. Removing any one of these factors will have an impact on the rodent populations. Therefore, proper sanitation is essential. This includes removal of trash and garbage piles, removal of grass, weeds and undesirable vegetation adjacent to buildings and elimination of potential rodent harborages. Proper storage practices that will permit regular cleaning and inspection are also important. It is necessary to practice good housekeeping that will limit areas where rodents can nest. Products should be placed on pallets, away from walls, so as to allow inspections, cleaning, and appropriate rodent management measures.

Figure 11. Important rodent management devices. A, plastic snap trap for rats; B,snap trap for mice; C, Ketch-all trap; D, Tin cat; E, different types of rodent baits (bottle with tracking powder); F, an opened bait station.



Another important method of rodent management involves the use of traps and rodenticides (Figure 11A-F). The home range for a rat is about 100 feet and that for a mouse is about 10 feet. This behavior should be taken into consideration when placing traps and bait stations. Traps and bait stations have to be placed every 8–12 feet for mice and 25–50 feet for rats. Trapping is one of the safest methods for managing rodents, because it does not involve the use of toxic materials. Traps are useful in areas where poisoned baits cannot be used, especially inside the plant. Also, dead animals can be easily located and discarded. To be most effective traps should be placed along normal runways with the triggers of spring traps placed adjacent to walls. Traps also need to be checked more frequently. The most commonly used traps are snap traps. These are usually baited with peanut butter, although there are newer models with expanded triggers that do not require baiting. Glue boards or sticky traps can also be used in the same manner as snap traps. However, rats are more difficult to catch on glue boards, because they are larger and stronger than mice. Automatic multiple catch traps or “Ketch-alls” are used to catch mice. There are two types of multiple catch traps-one uses a wind up mechanism that throws the mice into a chamber, and the other uses a trap door principle.

Table 3. Rodenticides used for management of rats and micea.

Active ingredient	Trade Name	Formulations	Dosage
Anticoagulants			
Brodifacoum	Talon, Enforcer, Ropax Attack, Weather-Blok	Loose pellets, bait blocks, packet bait	Single dose
Bromadiolone	Contrac, Maki, Boothill, Hawk	Loose pellets, bait blocks, packet bait	Single dose
Difethialone	Generation, Hombre	Loose pellets, bait blocks,	Single dose
Diphacinone	Ditrac, Ramik Green Tom Cat, Contrax-D	Packet bait, bait blocks, meal baits	Usually multiple feedings
Chlorophacinone	Rozol, Eatons AC 90	Packet bait, bait blocks	Multiple feeding
Warfarin	D-con, Final, Ferret, Final	Bulk pails, packet bait	Repeated doses necessary. Resistance noticed.
Non-anticoagulants			
Bromethalin	Vengeance, Assault, Trounce	Loose pellets, packet bait	Single dose
Cholecalciferol	Quintox, Rampage	Packet baits	One to three feedings
Zinc phosphide	Eraze, ZP, Ridal-Zinc	Pellets, tracking powder	Single dose.

[a] *Information as of October, 2001. Always check current labels for rates and use directions.*

Rodenticides can be classified into two main groups-anticoagulants and non-anticoagulants (Table 3). Anticoagulant rodenticides cause rodents to die of internal bleeding. The poison disrupts the blood clotting mechanism of the animal. All anticoagulants are slow acting, and death may occur from 3-10 days after bait consumption. The older anticoagulant rodenticides required multiple feeding by rodents, whereas the newer ones require a single feeding. Non-anticoagulant rodenticides cause death of rodents in various ways. Most of the non-anticoagulants are single dose poisons.

Bait shyness and resistance to rodenticides may sometimes be encountered. Baits must be fresh and attractive to the target rodents. Prebaiting with a non-toxic food source may sometimes be necessary to overcome bait shyness, and also to monitor rodent activity. However, all other competing food sources must be eliminated. Liquid baits may prove more effective in managing rodent populations in areas where water is a limiting factor. Tracking powders (rodenticides in powder form) are often used when baits are not well accepted or where food is abundant. These are usually blown into rodent burrows or wall voids. The rodents pick up the dust and ingest the toxicant while grooming themselves. Fumigation of rodent burrows is an effective rodent management method. However, only licensed and trained professionals or applicators should carry out fumigation of rodent burrows.

Three lines of defense are critical in any rodent management program. The first line is at the perimeter or fence of the facility to intercept rodents entering a facility from an outside harborage. Harborages such as tall weeds and other vegetation should be removed. Tamper-resistant bait stations should be placed at regular intervals along the fence. The second line of defense is around the building perimeter, and bait stations should be placed at regular intervals. In addition, woodpiles, empty boxes, logs, etc., near the building perimeter should be removed. Lawns should be mowed. Thick shrubs and ivy and vine growth on the walls should be removed. Trees and shrubs should be pruned. All water leaks should be fixed to reduce a source of water. Trashcans and dumpsters should be provided with tight lids and kept away from the building. The third line of defense begins with the building interior. All potential entry points like doors, vents, and pipes have to be sealed to exclude rodents.

Rodent populations reach an equilibrium that is determined by the availability of food, water, and harborage. In addition to births and deaths, there is constant immigration and emigration of populations that helps maintain this equilibrium. Poisoning and trapping will reduce rodent populations as long

as they are used. Once these efforts are stopped or reduced, the rodent populations build up rapidly. Rodent populations cannot be completely eradicated. However, populations can be brought down to a level where they do not cause aesthetic or economic damage. This can be achieved only by a modification of the habitat coupled with effective trapping and baiting programs.

Birds

An integrated pest management plan is necessary to tackle a bird problem. There are five basic approaches in managing a bird population. These include survey, sanitation, exclusion and habitat alteration, repellents, and population reduction. Surveys are necessary to identify the bird species and to study their activity patterns. Sanitation involves limiting or reducing access to food, water and shelter, in addition to regular removal of nests. Frequent clean up of spilled grain outside feed manufacturing plants is difficult and impractical. However, an effort should be made to change practices that cause grain spillage. Cleaning clogged drains, leaks, and standing water on roofs will help remove a water source. Persistent destruction of nests will greatly reduce populations of sparrows and pigeons.

The aim of exclusion is to deny access to enter or use the building as a nesting, roosting or loafing site. Plastic bird nets, covers, or ramps can be used to keep birds out of certain areas. The way a building is designed will provide harborage for large populations of birds. Therefore, building modifications play an important role in bird management. Various kinds of repellents are available that can either scare the birds away or make it difficult for them to use the building as a nesting or roosting site. Different wires, such as porcupine wires, bird barrier coils, spikes, electrically charged wires, and piano string have been used to physically prevent birds from nesting and roosting (Figure 12A). Sticky substances have been used, in certain situations, to repel birds.

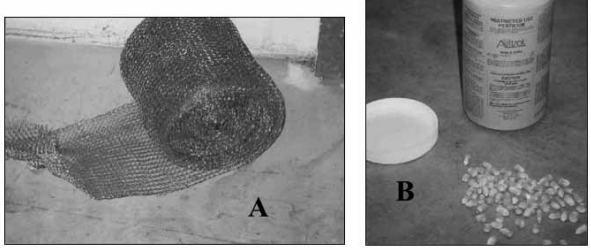


Figure 12. Bird management tools. A, Stuf-Fit copper mesh; and B, Avitrol laced whole corn.

Population reduction is mainly achieved by the use of toxic baits, traps, and sometimes, by shooting. Toxic baits have to be used with caution, as they may prove hazardous to non-target domestic animals or wildlife. Avitrol and Starlicide are two commonly used baits for pigeons and starlings (Figure 12B). Prebaiting with untreated grain will improve the efficacy of toxic baits. Pigeons and sparrows can sometimes be trapped near their loafing or feeding sites. Traps should be placed in the shade, and food and water should be provided. Leaving a few birds in the trap will serve as a decoy to lure more birds. Shooting is possible where relatively few birds are present. However, large-scale shooting programs should not be carried out because of safety reasons, and due to the possibility of bad publicity.

Summary

The magnitude of problems caused by insect and vertebrate pests may vary from plant to plant, and is directly related to the levels of sanitation and pest management practiced. Knowledge about biology, ecology, and behavior of pests is important for implementing proper pest management measures. Several techniques have been discussed for managing pests in raw ingredients and finished products. Pest management in the future may rely heavily on the use of pesticide alternatives, because federal regulations may cancel or severely restrict existing pesticides. Production of quality feed products is possible with the development and implementation of proper sanitation and pest management programs. All sanitation and pest management programs should be documented so that these programs can be evaluated or examined in case of product contamination or to verify consumer complaints. Training and education of plant sanitarians and employees is important for identifying pests and for recognizing the relationship between sanitation and pest infestations.

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Controlling *Salmonella* In Feedmills

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The link between the microbiological safety of food and the consequent health of the person eating the food is firmly entrenched. A component of disease avoidance for people and animals is to consume food that is pathogen free and so the animal feed industry has become increasingly vigilant in ensuring feed is free of potential pathogens such as *Salmonella*. Contaminated raw materials and contaminated feed may be deemed 'negative' unless adequate monitoring is conducted. Sampling site and the number of samples collected will determine the probability of finding *Salmonella*, eg. if feed contains 100 organisms/tonne and one 25g sample is used then there is a 1 in 400 chance of detecting 1 *Salmonella* bacteria and so a positive *Salmonella* result. Monitoring at points along the feed production process rather than finished feed alone will be helpful in isolating 'hot-spots' and indicating corrective actions. Greater vigilance will require increased activity on several fronts:

- wider participation in the raw material procurement process
- more vigilant raw material testing
- strict adherence to strong corrective actions with contaminated raw materials
- strict quarantine measures with contaminated raw materials
- greater commitment to monitoring and testing throughout the mill process
- stronger commitment to corrective and preventative actions in the milling process

The European Commission published a paper in 2000 ('White paper on food safety') that stated that the safety of food from animal origin begins with safe animal feed and that feed manufacturers, farmers and food operators have the primary responsibility for food safety. Assuming there is a commitment to the production of 'clean feed', the feedmill's approach needs to be comprehensive and integrated. The incorporation of a HACCP plan (Hazard Analysis of Critical Control Points) into a feedmill's Quality System is appropriate when aiming for *Salmonella* control and should include not only corrective actions, but also actions aimed at preventing *Salmonella* contamination of feed. Preventative actions can be strategic but routinely implemented. An approved supplier system, monitoring incoming feed ingredients, monitoring points along the feed production process, monitoring the mill environment, monitoring finished feed and feed transport vehicles are all relevant to an integrated control system.

Raw Material Receival and Storage

Due to the uneven distribution of *Salmonella* bacteria through a mass of feed ingredient (or finished feed) and difficulties with the logistical effectiveness of sampling from a large mass of material, it may be advisable to measure total enterobacteriaceae as an indication of microbiological status, and/or assume that all raw materials are a potential source of *Salmonella* contamination. When *Salmonella* is not found in a sample, it is certainly more appropriate to state 'not detected' rather than 'negative'. Whilst every raw material delivery should be physically inspected, samples of specified raw materials should be sent to an approved laboratory for *Salmonella* testing according to a prescribed schedule. This schedule will depend on:

- the type of raw material, eg. the emphasis is generally on protein meals
- the frequency of deliveries of certain raw materials, eg. every delivery may not need to be tested when there is more than one delivery per month
- the feed tonnage emphasis of the mill with respect to critical or 'sensitive' feed types
- the supplier's history, eg. a new supplier or suppliers with previous positive *Salmonella* test results

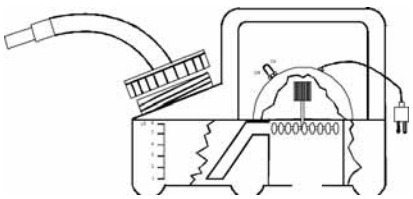
Whilst it would be desirable to have the more 'sensitive' raw materials tested for *Salmonella* or declared 'not detected' prior to their acceptance into the mill, this is not always possible. The next preference would be to place the delivery in a quarantine area at the mill and not use it in feed production until the laboratory result has been received, but this is also not always practical. Hence raw materials

may be used in feed production prior to receiving the laboratory result on *Salmonella* status. Apart from notifying the supplier and asking them to review their quality system, corrective actions upon receipt and use in feed of a *Salmonella* positive raw material should include:

- isolating and spraying the remaining raw material with a suitable liquid *Salmonella* inhibitor
- spraying a suitable liquid inhibitor or powder fogging with a suitable dry inhibitor (ie. solid state disinfection) any equipment that had been used to transport/convey the contaminated raw material (portable powder fogger shown in Figure 1)
- solid state disinfection by fogging the emptied bins that held the contaminated raw material with a suitable dry *Salmonella* inhibitor
- liquid spraying or solid state disinfection of areas used to hold the raw material if it was bagged or stored in loose bulk form
- flushing the entire intake and milling system with an appropriate quantity (eg. 500kg) of grain/grain byproduct mixed with a high concentration (eg. 5-10%) of a suitable dry *Salmonella* inhibitor – the intake system can also be flushed on a weekly basis to help prevent *Salmonella* growth; additional actions aimed at maintaining a 'clean' storage and milling system include a regular silo cleaning and sanitation programme (including powder fogging with a dry *Salmonella* inhibitor).

Figure 1. Portable dry powder duster used in solid state disinfection

Length x width x height	38 x 20 x 29 cm
Capacity of powder tank	max. 6 litre
Weight empty	4.2 kg
Alternating current	220 VAC
Electrical power	750 W
Flow rate	9 kg / h
Effective throwing range of powder	10 – 15 m



An alternative is to routinely treat high risk raw materials with an appropriate *Salmonella* inhibitor upon receival into the mill and therefore prior to use in feed production. Storage systems should be maintained in order to keep raw materials dry and the dust level in work areas should be well controlled. The results of a silo hygiene trial using a dry *Salmonella* inhibitor (based on organic acids and their salts) applied with a portable dry powder fogger are shown in Table 1. Swabs were taken at 4 points inside a silo and total enterobacteriaceae determined before fogging and then 24 and 48 hours after fogging (Adams, 1999).

Table 1. Control of total enterobacteriaceae (cfu/swab) by solid state disinfection with Sal CURB Dry (propionic & formic acids/acid salts) applied at 1kg/10 tonnes capacity

Swabbing point	Before fogging	+24 hours	+48 hours
Flange of outlet side	> 10,000	< 10	< 10
Flat side of hopper wall	> 10,000	< 10	< 10
Welded joint of hopper wall	> 10,000	< 10	< 10
Underside of wall panels	> 10,000	> 10,000	< 10

Table 2. *Salmonella* detection in UK feedmills

Source	Davies & Wray, 1997		Schrimpton, 1989
	No. of samples	% +ve	% +ve
Intake pits & augers	282	24.1	-
Ingredient bins & augers	637	12.7	-
Grinder	198	15.7	-
Mixer/weigher	348	11.8	69.0
Conditioner	-	-	32.0
Pellet press	308	7.5	4.0
Cooler	430	20.2	7.0
Finished product bin	484	15.1	13.0
Outloading gantry	210	10.5	-
Warehouse & bagging out area	202	8.4	-
On farm	-	-	19.0

The use of organic acid based products applied either as liquids (spraying) or powders (fogging) along the feedmilling process serve as both corrective and preventative measures that constitute a part of the integrated approach to minimising the risk of producing *Salmonella* contaminated feed. Solid state disinfection via fogging with dry powders is effective in enclosed areas and should also be used where the introduction of moisture is to be avoided and where the drying of wet surfaces is considered to be undesirably slow.

In-Process Sampling

In order to identify 'hot spots' and deploy necessary corrective actions and implement preventative actions, monitoring the feedmilling process is advised as a part of the integrated approach to controlling Salmonella (see Table 2 for survey data). Samples should be taken according to a set schedule. In-process sampling sites should include the meal intake pit, the inside top surface of the mixer and the inside surfaces of the pellet press door, cooler, bulk out-loading bins and bag packing bins. Material can be scraped from the site with multiple scrapings combined and placed in a sterile container.

Mash Feed and Pelleted Feed

Table 3. Feed Salmonella incidence survey results from the USA (Jones et al, 1991) and Canada (Blackman et al, 1993)

Source	USA		Canada	
	No. of samples	% +ve samples	No. of samples	% +v samples
Mash	40	35.0a	169	22.5a
Pellet	79	6.3b	100	4.0b

The aim is to manufacture feed to ensure no risk of *Salmonella* contamination during processing. Finished feeds selected for testing should represent the more critical and 'sensitive' feed types. An appropriate dry or liquid *Salmonella* inhibitor should be included in the more sensitive mash feeds as a preventative measure. Conditioning temperature and retention times should be monitored for pelleted feeds to ensure they meet the minimum standard set by the feedmill. Whilst these standards may be quite difficult to arrive at, they should be determined by the feedmill for the formulations of concern (published *Salmonella* survey data are shown in Table 3). If bypassing the cooler is not possible during start-up of the pellet press, then a *Salmonella*a inhibitor should be included in the first 3 batches of feed produced and/or until the minimum conditioning temperature is achieved. The press should be cleaned on a weekly basis and any build-up of wet material removed from inside the door and chutes – the inside surfaces of the door can then be sprayed or powder fogged with a *Salmonella* inhibitor. The weekly flush material referred to above should also pass through the press and cooler. A *Salmonella* inhibitor may also be included in pelleted/crumbled feed in order to maintain its improved microbiological status beyond the feedmill and help to ensure its improved *Salmonella* status.

Salmonella inhibitory products based on blends of particular organic acids and formaldehyde can also offer valuable assistance in controlling *Salmonella* contamination in raw materials and in feed. Data demonstrating this effectiveness in *Salmonella* contaminated meat meal and in laying hen mash that contained the same contaminated meat meal is shown below.

Table 4. Elimination of *Salmonella* contamination in meat meal and in layer mash

Sample	Treatment	Rate	Detection @ 4 hours after treatment	MPN (cfu/100g) @ 2 days after treatment
Meat meal – control	-	-	Positive	240
Meat meal – treated	Sal CURB RM Extra Liquid	3 kg/t	Negative	-
Mash feed – control	-	-	Positive	9
Mash feed – treated	Sal CURB RM Dry	2.5 kg/t	Negative	-

No raw materials should be stored near the cooler air intake and the area around the cooler should be kept clean and free of dust. The inside surfaces of the cooler should be kept free of moist feed build-up and should be powder fogged on a weekly basis with a dry *Salmonella* inhibitor. The standards used along with the cleaning and sanitation programme should be reviewed when *Salmonella* positive samples are reported. The frequency of cleaning and sanitation using *Salmonella* inhibitory products may need to be increased.

Application Equipment

Solid state disinfection requires special applicators to distribute the dry powdered disinfectant products over the surfaces of interest. Two special applicators for quick and appropriate distribution of solid state disinfection products have been developed. These are suitable for all kinds of feed production machinery, storage silos, transportation systems, conditioners, coolers and vehicles. These applicators offer a fast and efficient way to disinfect inaccessible places within the mill system and also larger areas such as grain silos. Figure 1 shows a portable powder duster which is suitable for vehicles, production machinery, conveying lines and small silos. Figure 2 shows a mobile silo duster which is suitable for larger production and storage areas as well as floor surfaces and larger capacity silos. Figure 3 illustrates effective liquid spraying arrangements suited to treating raw materials and finished feed.

Figure 2. Mobile silo duster used in solid state disinfection

Length x width x height	150x80x130cm
Capacity of powder tank	max. 100 litre
Weight empty	30 kg
Alternating current	220 VAC
Electrical power	3000 W
Flow rate	100 kg / h
Maximum elevation	30 m
Effective throwing range of powder	10 - 15 m

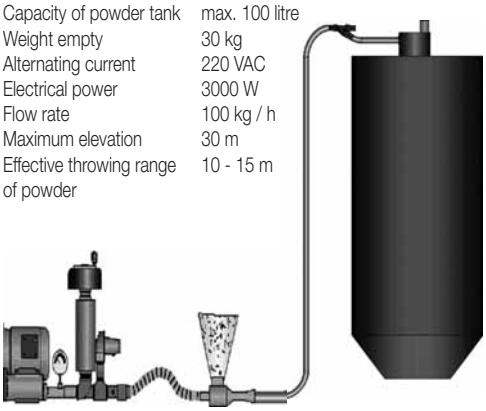
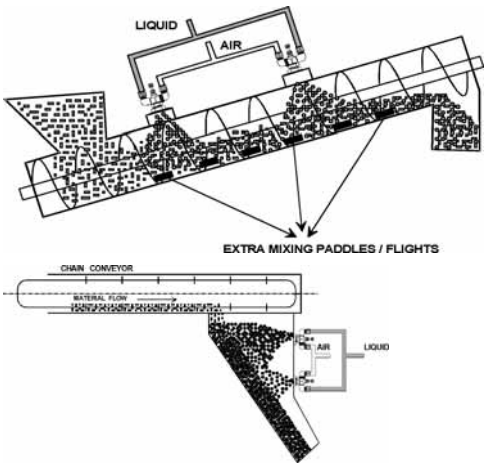


Figure 3. Schematic representation of effective raw material and feed spraying systems

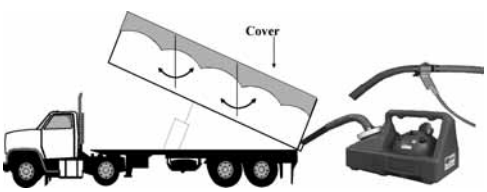


Conveyance to Bins and Feed Delivery

Feed must remain free of *Salmonella* during transfer from the mill to storage silos and bins. Equipment that allows build-up of feed and moisture penetration should be regularly inspected and cleaned and samples submitted for *Salmonella* detection as per the prescribed schedule. Elevator boots should be cleaned out regularly and liberally dusted with a dry *Salmonella* inhibitor. An outloading/bagging out bin sanitation programme should be in place involving powder fogging with an inhibitor. The weekly grain/grain byproduct/*Salmonella* inhibitor flush should be allowed to pass right through to bulk outloading and bag packing bins. The finished feed storage area should be kept clean and sanitized. Feed delivery trucks should be dedicated to feed transportation and not used for transporting raw materials. A truck hygiene programme should operate and may include solid state disinfection of emptied trucks with a dry *Salmonella* inhibitor.

Contamination of feed after it leaves the feedmill also presents a challenge. This requires not only good hygiene practices throughout the feed production process, but also with feed delivery systems and subsequent storage conditions on-farm. Contamination from rodents, birds or the environment is likely to be local in distribution and not homogeneously distributed through the material.

Figure 4. Solid sate treatment of feed transport vehicles



Modes of Anti-Bacterial Action for Organic Acids

Salmonella inhibitory products based on organic acids can be routinely used in accordance with a strategic preventative action programme in the mill and a corrective action schedule ('Feedmill *Salmonella* Control Programme' booklet, Kemin (Asia) Pte Ltd). The inhibitory effect of organic acids on bacteria will depend on a range of factors including:

- dissociation constant(s) (pKa) of the acid(s)
- anion species
- molecular size(s) of the acid(s)
- acid solubility characteristics
- acid volatility
- quantity of acid(s)

The modes of antibacterial action can be summarized as follows:

- **destruction of the 'proton motive force' inside the cell**

Energy as ATP needed by the cell is derived from glycolytic pathways in anaerobic microbes and by the electron transport system in aerobic microbes but substrates must be transported into the cell before energy can be produced. Active transport of substrates into the cell is coupled with the cell's energy yielding processes and the pH difference across the cell membrane. The cell membrane restricts the entry of H+ or OH- ions into the cell. Accumulated protons are ejected from the cell creating chemical and electrical gradients across the cell membrane. The anti-bacterial mechanism of the acid that disrupts the cell's proton motive force (ie. capacity to eject protons) requires that the undissociated (ie. intact) acid enters the cell. It will then dissociate at the pH of the cytoplasm (approx. 7.0). The protons (H+) thus produced must then be ejected from the cell in order to maintain the cell's internal pH and the required gradients across the cell membrane. The increased H+ concentration and the required ejection process disrupts the coupling of the cell's energy production with the transport of substrates into the cell. The increase in acidity of the cell's cytoplasm will also inhibit the synthesis of certain macromolecules such as cell wall components, DNA, RNA, lipids and proteins. The net effect is that the cell expires due to progressive energy depletion.

Table 5. D values (hours) for tested Salmonella strains

Salmonella strain	Formic acid	Propionic acid
Kedouga 131a/1	5.2	0.6
Enteriditis PT4	6.3	0.8
Typhimurium DT49A	5.5	0.8
Typhimurium DT14	8.5	0.7
Virchow	4.3	0.6
Average D value	6.0	0.7

This mechanism is well illustrated by a study, which examined the capacity of formic acid and propionic acid to kill *Salmonella* strains (Cherrington et al, 1991). *Salmonella* strains were incubated at pH 5 with 0.5mol/l of either formic or propionic acids and D values were determined (i.e. the time taken for 90% of the cell population to die). Table 5 below shows the results obtained.

The explanation provided by the authors was that at pH 5 a greater proportion of propionic acid would remain in the undissociated form compared with formic acid, ie. 43% for propionic versus 5% for formic acid. This difference arises due to the pKa values being 4.87 for propionic acid and 3.75 for formic acid. Thus there was substantially more undissociated propionic acid than formic acid that could enter the Salmonella cells and disrupt their proton motive force. If this mechanism was the sole means by which organic acids killed bacteria, then bacterial inhibition would reflect the dissociation constants of the acids. This is not the case and hence there are other antibacterial mechanisms derived from the varying properties of organic acids.

Chung and Goepfert (1970) also tested acids with respect to their capacity to inhibit the growth of *Salmonella* and found that the extent of pH reduction required to completely inhibit growth varied with the acid. For example, the pH required to completely inhibit growth with citric acid was 4.05 compared with 5.5 for propionic acid. This indicates that pH reduction per se is not a crucial requirement of the antibacterial process.

- **disruptive effect of the anion**

The salts of organic acids are well known to possess antibacterial and antifungal activity and indeed salts of propionic acid are widely used for mould inhibition in feed and grain. As long ago as 1945 Olson and Macy found that calcium propionate was effective in preventing surface mould on butter (and was more effective than the sodium salt). A further demonstration of the antifungal activity of acid salts can be seen from results obtained by Rahnema and Neal (1992) who evaluated the efficacy of mould inhibitors with maize under laboratory conditions (Table 6). Inhibitors were added at 2lb/t with 15% moisture maize and at 4lb/t with 18% moisture maize. Product formulations containing salts of organic acids may also be preferred over un-buffered acid product formulations on the basis of occupational health and safety for staff working in the feedmill.

Table 6. Effect of propionic acid and acid salts on mould development in maize

Inhibitor	Days to mould with 15% moisture maize	Days to mould with 18% moisture maize
Control	6.3	3.7
Propionic acid	13.0	8.7
Acid salts*	12.7	10.0

** Myco CURB Liquid contains predominantly salts of propionic and benzoic acids*

Table 7. Survival % of *E.coli* strains to various organic acids at pH 3

Strain	Serotype	Isolate Source	Acetic	Lactic	Malic	Citric
ATCC 35150	0157:H7	Clinical	39	0.01	68	66
ATCC 43895	0157:H7	Hamburger	79	0.08	51	67
505B	0157:H7	Beef	1.8	<0.01	0.1	12
NCTC 12079	0157:H7	Clinical	0.08	0.01	0.01	0.1
30-2C4	0157:H7	Clinical, salami	100	6	85	94
C9490	0157:H7	Clinical, 'Jack-in-the-box' hamburger	6.7	0.06	78	72
1267	0157:H7	Clinical	100	3.3	76	100
W2-2	0157:H7	Poultry	2	<0.01	6.3	10
NCTC 10964	0157:K88a,c:H19	Piglet	34	0.2	77	84
NCTC 9001	01:K1:H7	Clinical, urine	0.02	<0.01	2	16
NCTC 10865	020:K84:H26	Clinical	62	2.1	100	69
J1	Unknown	Clinical, healthy volunteer	15	0.05	2.1	86

The authors concluded that for most *E.coli* strains the antibacterial effect was specific for lactate because acetate, malate and citrate did not cause significant cell death. It is noteworthy that strain 30-2C4 was the most acid tolerant yet lactate resulted in a 94% kill compared with only a 6% kill for citrate. The pH conditions of this in vitro work (ie. 3) were below the pKa values of each acid and so a larger proportion of the acids would remain in the undissociated form. Indeed, the cytoplasmic pH rapidly declined in the presence of lactic acid, which supports the proton motive force disruption antibacterial mechanism. However, the authors state that pH reduction of the cytoplasm alone could not fully explain the cause of cell death and suggest that the lactate ion may compromise the cell's membrane permeability to protons and/or the capacity to pump protons out of the cell – hence an effect of the anion per se within the cell. The specificity of the lactate ion over and above the effect of the undissociated acid concentration is supported by consideration of the pKa value for acetic acid being 4.76 and for lactic acid being 3.86 which would equate to a greater concentration of undissociated acetic acid than lactic acid at pH 3. Despite this, lactate was demonstrably more effective at killing these *E.coli* organisms. Russell (1992) points out that whilst certain microbes may be tolerant of lowered intracellular pH, anion accumulation in the cell can also be the cause of organic acid toxicity to the cell. This anion effect can be quite specific as shown in the table above.

- **effect on the cell caused by the H+ outside the cell**

pH of the medium is a factor that influences the ability of bacteria to survive, grow and develop. Bacteria will not survive and grow if the pH of the medium is outside the bacteria's required pH range. The ability of an acid to lower the pH of the medium outside the cell is considered to be a pH effect and so an effect of the dissociated acid and generation of H+ outside the cell. Whilst normally the permeability of the bacterial cell membrane to charged molecules is limited, certain acids can disrupt the cell membrane and then allow entry of H+ into the cell's cytoplasm.

- **effects of both the undissociated and the dissociated acid**

Eklund (1983) concluded that the antimicrobial action of sorbic acid is derived from both the undissociated and dissociated acid forms supported by Stratford & Anslow (1998) defining the multiple antimicrobial mechanisms for sorbic acid to come from its weak-acid action, a membrane-active mechanism and a specific metabolic inhibitory action. The model for *E.coli* growth inhibition from acids was described by Salmond et al. (1984) as coming from an unidentified metabolic function derived from the undissociated acid and acidification of the cytoplasm.

- **synergistic effects of acids**

Synergistic effects are not uncommon in biology and this can also be found with organic acids and is not surprising based on the multiple mechanisms of antibacterial action as described above. References to this synergy can be found in the literature,

Table 8. Synergy of acids against *Salmonella* in meat meal and fish meal

		Salmonella reduction (%)			
Meal	Treatment	10 min.	30 min.	60 min.	24 hours
Meat meal	10kg formic acid	44.9	59.6	71.5	86.1
	10kg propionic acid	46.3	65.9	76.3	85.7
	3kg combination*	21.4	46.8	64.1	80.7
Fish meal	10kg formic acid	48.2	56.4	62.8	84.0
	10kg propionic acid	54.5	70.5	77.5	81.3
	3kg combination*	25.9	50.2	69.9	84.6

*Sal CURB

eg. between propionic and formic acids with respect to Salmonella control (Thompson & Hinton, 1997). The synergistic effects of these acids against *Salmonella* in meat meal and fish meal is also suggested by work from a UK laboratory (Table 8). The starting contamination level was very high at 3,850 organisms per gram for the meat meal and 4,560 for the fish meal. Whilst 3 kg of the individual acids was not applied, 3kg of the acid combination yielded equivalent *Salmonella* reductions as 10kg of the individual acids.

Summary

1. Assuming there is a commitment to the production of 'clean feed', the mill's approach needs to be comprehensive and integrated.
2. The incorporation of a HACCP plan into a feedmill's Quality System is appropriate for *Salmonella* control and should include not only corrective actions, but also routine actions aimed at preventing *Salmonella* contamination of feed.
3. An approved supplier system, monitoring incoming feed ingredients, monitoring points along the feed production process, monitoring the mill environment, monitoring finished feed and feed transport vehicles are all relevant to an integrated control system.
4. The judicious and strategic application of liquid and dry organic acid based *Salmonella* inhibitors will help ensure that raw materials, feed manufacturing facilities, feed, transport vehicles and feed silos are kept free from *Salmonella*. Organic acid based products containing formaldehyde are also very effective against *Salmonella* and can be used when regulations permit.
5. Programmes need to be implemented within a framework of good management and attention to all environmental factors which could introduce or disseminate *Salmonella* – effective rodent and wild bird control is always important.

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