Strategies for the assessment of livestock feed ingredient quality

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Summary

Potential exists to improve current strategies and methods employed to assess livestock feed ingredient quality. Of paramount importance to any assessment procedure is representative sampling of the test ingredient. Sampling must be sufficient to facilitate the most sensitive form of analysis, such as that conducted for chemical residues. Arguably, the greatest proportion of time and effort directed towards the assessment of livestock feed ingredient quality should be focussed on the sampling process. Recent research has resulted in the development of rapid methods for the direct assessment of the nutritional quality of feed ingredients for pigs, poultry and ruminants and significant potential exists to improve the use of this technology in commercial animal and feed production systems. Opportunities also exist for the development of multi–screen ELISA assays for chemical contaminants, while a number of ELISA based test kits are in existence for specific mycotoxins. Quantitative analysis of weed seeds may be achieved through the use of image analysis, but there is an urgent need for rapid methods for the assessment of natural plant toxins such as pyrrolizidine alkaloids. The cost benefits of assessing nutritional quality can be clearly demonstrated, but when compared against the risks, analysis of ingredients for contaminants requires more strategic thought.

Introduction

Current routine procedures for the assessment of livestock feed ingredient quality prior to inclusion in compound feeds are far from adequate. Our ability to rapidly and accurately assess the nutritional quality and subsequent nutritional value of a feed ingredient is limited and restricts our capacity to optimise overall livestock production efficiency. For example, a typical testing procedure for a grain received at a feedmill might involve collection of a sample from the truck during unloading, a visual inspection of the grain for obvious signs of grain damage or contamination, and analysis of the sample for moisture and crude protein content. This process may provide the end–user with some comfort that a quality assurance protocol is in place, however a procedure of this nature can only be considered as a very rough guide to ingredient quality. It will provide no data on the presence or absence of chemical residues or mycotoxins, weed seeds may be identified but the level of toxin contributed will not be quantified, and the chemical components measured correlate poorly with nutrient contributions to the target animal. Furthermore, if more detailed analysis of a sample is pursued, the length of time taken to complete the analysis is often too long to be useful. For these reasons, a review of practical strategies for the assessment of livestock feed ingredient quality is long overdue.

Research over recent years has improved our ability to define the nutritional requirements of livestock, largely through the use of simulation models (e.g. Black *et al.* 1986). This advance necessitates more refined definition of the nutritional value of feed ingredients if the nutritional requirements of the target species are to be met as accurately as possible. Some progress has been made in the rapid assessment of the nutritional quality of feed ingredients (Morgan 1995; van Barneveld *et al.* 1999; BECAN Consulting Group 1999; Wrigley 1999), yet these techniques are still to be adopted widely. There is a need to increase awareness of these methods and of the potential benefits that could be derived from their routine adoption.

A recent survey of Australian stockfeed manufacturers (BECAN Consulting Group 1999) suggests a high awareness of potential grain contaminants and the associated risks but a limited capacity to identify these contaminants and a limited knowledge of the cost–effectiveness of analysis. It is clear that with the advent of more rapid methods of analysis, some end–user education is required in relation to grain sampling, the frequency of use of rapid tests and the course of action in the event that a contaminated sample of grain is identified.

To provide some practical guidelines for the assessment of livestock feed ingredient quality prior to

inclusion in mixed feeds, this paper will:

- Detail adequate sampling procedures for grains and other feed ingredients
- Outline rapid, accurate methods to predict nutrient contributions from feed ingredients
- Discuss the potential for analysis of grain contaminants
- Provide an estimate of the cost–effectiveness of sample analysis

Ingredient sampling

Ingredient sampling is the most critical step in the assessment of livestock feed ingredient quality. A sample that is not representative can result in misleading analysis with the consequences being unnecessary rejection of an ingredient, or acceptance of an ingredient that will lead to losses in livestock production efficiency. In this instance it is fair to say that the wrong answer arising from incorrect sampling is worse than no answer.

The degree of accuracy required when taking an ingredient sample will differ depending on the type of analysis planned. If only one sample is taken from a load, it will need to be adequate for the most sensitive form of analysis.

Sampling for nutritive value

A survey of variability in grain protein content conducted by the Canadian Grain Commission (1999) demonstrates the need for representative sampling when assessing nutrient contributions from an ingredient (Table 1).

Given that significant variation in the nutrient content of grains can occur even within a single plant, sampling of bulk loads must be performed methodically and meticulously if a representative sample is to be obtained. The following protocols derived from Hellevang *et al.* (1992), Richardson (1995) and the Canadian Grain Commission (1999) are likely to result in a representative sample from bulk loads and bagged ingredients, respectively.

Sampling bulk ingredients

Samples of bulk ingredients are most commonly collected using a spear sampler at various points in the load. While accepted by many, a more representative sample may be obtained from a grain stream falling from the end gate of the truck as follows:

- Use an appropriate sampling device that will collect grain from the entire stream without overflowing. The grain stream may need to be controlled to allow the sampler to pass through the stream without overflowing
- Make sure the sampling container does not contain seeds or other material before sampling
- Samples should not be taken from the first or last portions of a load since these areas do not provide a representative cross section
- Samples should be collected from the grain stream where the stream is established, approximately 30 cm below the end–gate of the truck
- The entire stream must be cut (sampled) with a side to side sweep of the sampler, cutting the full thickness of the stream—front to back. The sampler should be held in a horizontal position while passing it through the grain stream to facilitate even filling of the sampler
- At least two, preferably more, samples should be collected at regular intervals, with intervals selected so that the entire lot of grain is represented. For example, three samples could be taken in the middle of each third of the load. Each sample should be approximately 2 kg and bulked for the entire load
- The quantity of sample sent for analysis (500–1000 g) will be significantly less than the quantity collected during sampling. The portion used for analysis must be divided so that it is representative of the whole sample. Hand mixing and subsampling tends to cause fines to settle to the bottom of the container. Segregation occurs in the receiving container when pouring from

Table 1 Variation in grain protein content (g/kg) at different sampling levels (Canadian Grain Commission 1999).

Source of variation	Range in protein content (g/kg)
Kernels within a head	40
Heads from one plant	20
Plants within one row (0.55 metres)	30
Rows within one apparently uniform field	60
Farms delivering to one elevator point	50
Farms within one crop district	60
Farms within a province	80
Farms within Western Canada	110

container to container, so grain used for analysis needs to come from a cross section of the sample as it is being poured. Place a container on the unloading grate or tarpaulin, then with a sweeping motion pour the grain from the sample while allowing the stream to move across the stationary container. The grain should be poured at a rate so that after several passes the sample container is empty at the time the desired quantity for analysis is collected. The procedure should allow collection of a subsample for analysis and a subsample for storage and future reference if required

- The sample must be handled in a manner that does not allow the condition of the sample to alter from the time it was collected. Samples must be labelled with the date collected, the source, the type of sample, and any other relevant information
- Duplicate determinations are recommended for all variables measured

Sampling bagged ingredients

A slotted grain trier or spear should be used for bagged ingredients and approximately 400 g of sample should be collected from each bag sampled. For lots of one to ten bags, all bags should be sampled. For lots of eleven bags or more, at least ten bags should be sampled. Samples can be bulked and a subsample analysed in duplicate, or at least three separate samples can be analysed and the results averaged.

Sampling for moulds and mycotoxins

The difficulties associated with sampling and analysing for moulds and mycotoxins was summarised by van Barneveld (1999a) and include:

- There is a wide range of moulds and mycotoxins that can potentially occur in grains and grain by–products
- Not all moulds that produce mycotoxins are visible
- The presence of a mycotoxin producing mould does not necessarily mean the mycotoxin is active (for example, Chelkowski *et al.* (1983) tested 636 samples of wheat, oats, barley and maize in 1979–81 to find only three had zearalenone at levels of 200, 700 and 2000 µg/kg, respectively. Fungi forming zearalenone were present in 28% of samples of cereal grain and about 48% of *Fusarium* fungi tested were able to synthesise the mycotoxin
- The anti–nutritional effects of moulds and mycotoxins are not always easy to detect in the target species
- Analytical methods are usually specific for a particular mycotoxin
- Many of the clinical symptoms associated with the presence of mycotoxins can be confused with other disease vectors
- Moulds and mycotoxins can be distributed unevenly in a sample of grain or feed

In addition, our ability to test for the presence of moulds and/or mycotoxins can be limited by the accuracy of the analytical methods employed. For example, sample size and sampling method have limited effect on the variability of vomitoxin or deoxynivalenol test results for barley (Anon 1998). Increasing sample size did not significantly decrease variability of test results, sample selection method did not appear to cause greater variability and no single factor was identified that will reduce variability of these measurements in an easy and cost–effective manner. It was concluded that the bulk of the variation observed in this study was due to the analytical methods employed.

When variability in analytical methods can be minimised, the influence of sampling method on the accuracy of analysis for the presence or absence of moulds and mycotoxins can be significant. Howell *et al.* (1984) used a 12.5 kg sample of whole grain maize and an 11 kg sample of soybean meal, both shown to be contaminated with approximately 50 µg/kg of zearalenone, to demonstrate the distribution of the mycotoxin in a sample. Each sample was divided into 100 sub–samples and the level of zearalenone in each was measured. The distribution of zearalenone in 40 x 110 g samples of soybean meal was shown to be normal at a mean value of 50 µg/kg with a variance of 77. The distribution of zearalenone in 100 x 125 g samples of maize was best described by a $\log_e$ normal distribution when the mean value was 52 µg/kg with a variance of 14126. It is concluded that for soybeans the proposed sampling technique of 3 x 4 kg aggregate samples each composed of 20 x 200 g incremental samples was adequate, but for maize the aggregate samples should be bulked together to give a 12 kg sample composed of 60 x 200 g incremental samples. For maximum accuracy more than one 12 kg aggregate sample should be used.

Given the low incidence of moulds and mycotoxins in Australia and the difficulties associated with accurate analysis, sampling for analysis is unlikely to be routine, but when completed it must be completed meticulously.

Sampling for chemical contaminants

Recommendations for the sampling of feed ingredients for chemical contaminants were made by the BECAN Consulting Group (1999). Sampling procedures were as described above with the following qualifications for sample size and sampling frequency:

- Sampling is undertaken by taking at least three, preferably five, primary samples at random from the commodity as presented
- Each primary sample must be the same size (e.g. weight or volume). The primary samples are mixed

to form the sample for analysis. Mixing should be complete to ensure the sample analysed is uniform

- Equipment used in the collection and transfer of samples must be clean and of an inert structure. The equipment must not be exposed to pesticides from any source (other than through the grain being sampled) during storage or use. Details of sample size and other sample requirements for various commodities are provided in Table 2.

Sampling for insects

Tools such as the 'Stored Grain Advisor' (Version 3.02; Instructional Media Centre, Kansas State University, Manhattan, Kansas) can be used for information on how to sample stored grains (particularly wheat) for insects in addition to providing strategies for the long term storage of grains, insect identification and modelling the effects of storage and holding conditions on insect damage. Information is available on sampling equipment (Figure 1) and the source of this equipment. The sampling module can be used to develop an insect sampling program for specific storage situations. Based on the number of samples taken, it will calculate 95% confidence intervals for insect trap and probe samples. Estimations can also be made of the probability of detecting insects in grain based on insect density and the number of samples taken.

Sampling for weed seeds

When assessing the consequences of weed seed contamination from a livestock perspective, the biggest consideration is the natural toxin that the weed seed contains. If a weed seed does not contain a toxin, its

Table 2 Sample sizes and other sample details for analysis of chemical contaminants in various commodities (BECAN Consulting Group 1999).

Commodity	Minimum size* (kg) of primary sample (5 or more primary samples taken)	Minimum size* (kg) of primary sample (3 or 4 primary samples taken)	Minimum size* (kg) of sample despatched to laboratory
Cereal grains 0.7	0.8	0.5	
Other grains 1.3	1.5	1.0	
Forage/Fodder 1.3	1.5	1.0	
Hay/Straw 0.7	0.8	0.5	
Silage 1.3	1.5	1.0	
Wet feeds (e.g. Pomace, Brewers waste)	1.3	1.5	1.0
Other (e.g. cane tops, pineapple tops, etc.)	1.3	1.5	1.0

*The minimum sample size assumes primary samples will be taken and the remainder of each primary sample will be retained for further testing if required. A sub–sample of each primary sample will be mixed together to form the laboratory sample.

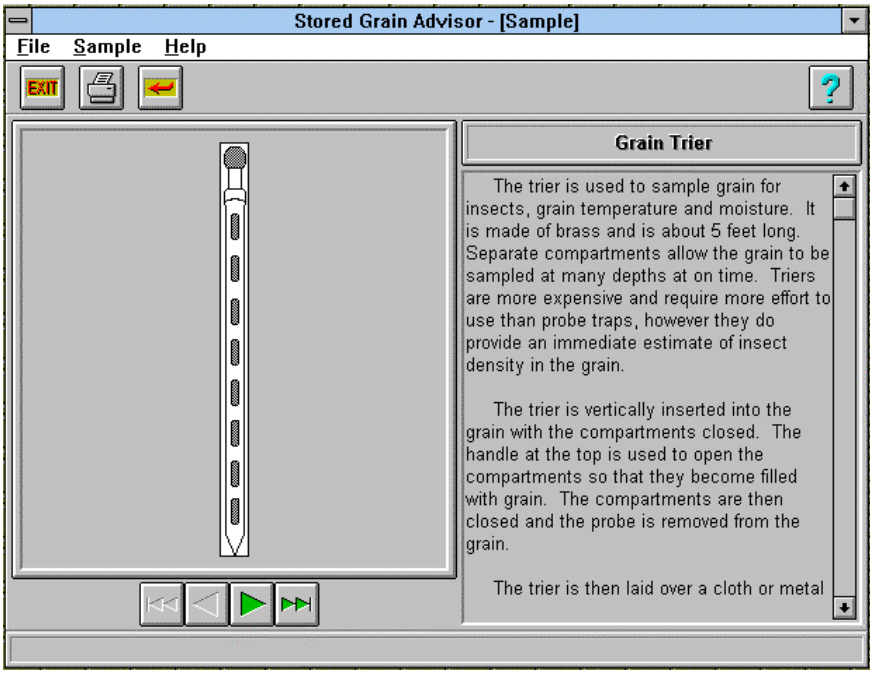

Figure 1 Example of the information provided by the 'Stored Grain Advisor' (Version 3.02; Instructional Media Centre, Kansas State University, Manhattan, Kansas).

presence in a grain sample may be of limited concern, except for the effect it may have on our ability to define the supply of amino acids and energy that could be expected from the grain sample in question (van Barneveld 1999). To quantify the presence of plant toxins, sampling procedures similar to those employed for chemical contaminants should be employed.

Rapid assessment of nutritional quality

Having collected a representative sample of a feed ingredient, it is desirable to assess that sample for nutritional quality prior to inclusion in a mixed diet. To accomplish this, rapid and accurate methods of analysis for nutritional parameters such as available energy and available amino acids are required at the point of receival.

To date, rapid assessment of nutritional components of feed ingredients is restricted to crude protein and moisture content. For monogastrics, these measures correlate poorly with available energy and available amino acids (van Barneveld *et al.* 1999b). The studies completed to date (e.g. Batterham *et al.* 1980; Morgan and Whittemore 1982; Yin 1993) all conclude that neutral–detergent fibre is the best predictor of the nutritive value of feed grains for pigs. It is likely that more specific non–starch polysaccharide components will give more accurate correlates with nutritional value, but further research is still required to define these relationships.

Current methods for accurately measuring the available energy content of feed grains for livestock involve detailed animal experiments. Hence they are no use when it comes to assessing samples as they are delivered to grain receival points or sites of stockfeed manufacture. To achieve this, an objective analytical method is required that meets the criteria of being rapid, accurate, inexpensive, safe, easy to use and environmentally friendly. Candidates for this type of analysis for the measurement of the nutritive values of feed grains were suggested by Wrigley (1999) and include:

Single–kernel characterisation system determines the mass, thickness, moisture content and hardness of individual grain kernels. The only potential for this type of system to predict available energy content would be through the addition of near infra–red spectroscopy equipment.

Rapid visco analysis based on the principles of the Falling Number test aims to determine the extent of starch breakdown due to the activity of the starch hydrolysing enzymes of germination. As rapid visco analysis provides indications of the pasting properties of starch in grain, there is potential for correlation with starch digestibility and hence energy contributions. This technique does, however, involve wet chemistry which can limit the speed of testing.

Enzyme–based test kits use specific enzymes to hydrolyse a target compound, usually a complex carbohydrate. As these methods are well suited to identifying classes of polysaccharides that can influence nutritional quality, they have reasonable potential as a possible method for the prediction of available energy. Unfortunately, these methods are less than rapid.

Near infra–red spectroscopy (NIRS) analysis depends on detecting the presence and intensities of spectral bands from overlapping overtones corresponding to various chemical bonds, particularly C–H, O–H and N–H. NIRS represents one of the truly rapid forms of analysis and requires limited sample preparation. The success of the technique relies heavily on the composition of the base sample set used to derive calibrations. There is potential to apply NIRS in two ways to predict the available energy content of feed ingredients — either by quantifying factors that may correlate with available energy content, or by simultaneously accounting for those factors that influence available energy content (such as starch, non–starch polysaccharide and protein content).

As NIRS is already widely in use at grain receival points for the assessment of moisture and energy, and given its unrivalled combination of speed, accuracy and simplicity (Osborne *et al.* 1993), it holds the greatest potential in any strategy for the assessment of livestock feed ingredient quality.

Use of NIRS for the assessment of feed ingredients for pigs

Recent research completed by van Barneveld *et al.* (1999) has demonstrated that NIRS can predict the digestible energy (DE) content of cereals for pigs within 0.38 MJ/kg, which is comparable to the accuracy achieved when using *in vivo* reference methods. Examination of difference spectra for the samples within one grain type (barley) having the highest and lowest DE values reveal that there are a number of factors (hemicellulose/cellulose, starch, lipid, protein etc.) influencing the DE predictions. Validation studies completed to date demonstrate that this calibration can successfully predict the DE content of wheat samples ranging in DE content from 13.8–14.7 MJ/kg and barley samples from 10.7–13.2 MJ/kg. Further, this analysis can be completed with equal degrees of accuracy on both whole and milled samples of grain.

Use of NIRS for the assessment of feed ingredients for poultry

The development of NIRS calibrations to predict apparent metabolisable energy in feed grains fed to poultry has met with variable levels of success (van Barneveld 1998a). A large factor contributing to this may be that apparent metabolisable energy

measurements in poultry can be highly variable due to inherent individual bird variation. The extent of the influence of individual bird variation on apparent metabolisable energy measurements has been demonstrated by Hughes and van Barneveld (unpublished data). When a single diet containing barley was fed to 96 individually housed broiler chickens (17 days of age) simultaneously under identical conditions, the apparent metabolisable energy measurements ranged from 12.25 to 13.5 MJ/kg DM. Despite this, Windham *et al.* (1994) and Leeson and Valdes (1996) demonstrated close agreement between predicted and *in vivo* apparent metabolisable energy content of selected ingredients.

Use of NIRS for the assessment of feed ingredients for ruminants

The application of NIRS to predict the available energy content of feed grains for ruminants requires additional considerations. A confounding factor in addition to the inherent variability within feed ingredients used in ruminant rations is that the energy and amino acid availability of any feed fed to ruminants is heavily influenced by the other components of the ration. Many rumen variables such as flow rate, rumen pH and nitrogen levels will affect the nutritive value of a diet ingredient. For example, the relative nutritive value of a cereal grain depends on its proportion in the total diet, its degree of processing, other dietary constituents and the level of productivity of the animal. Consequently, variability in response to grain feeding has a lot to do with other dietary factors rather than simply the variability in grain nutritive value. For these reasons, the use of NIRS to predict the nutritional quality of feed ingredients for ruminants is more difficult due to the interactions that take place between different dietary components within the rumen. NIRS may still have a role, however, when combined with rumen function and amino acid and energy computer simulated growth models. Rumen function models will evolve with the capacity to account for a variety of rumen inputs and predict the subsequent outputs. NIR could be effectively used to measure the inputs required by such simulation models (e.g. protein, moisture, non–starch polysaccharide and starch content of ingredients), and the subsequent use of computer simulation models would facilitate the accurate prediction of nutritional quality regardless of the feeding regimen (Figure 2).

Flinn and Downes (1996) have focussed on the development of calibrations for functional properties of ruminant feeds such as *in vivo* dry matter digestibility, voluntary feed intake and animal production. Dry matter digestibility has potential for use in the prediction of energy availability in grains for ruminants, however, this measurement will not account for interactions that occur between grains and forages in the rumen environment.

Based on the above descriptions, it is clear that significant advances have been made in our ability to directly assess the nutrient contributions from various feed ingredients for pigs, poultry and ruminants. Further research is underway to refine these methodologies, but they hold significant potential to improve livestock production efficiency in their current form and warrant more attention from nutritionists and stockfeed manufacturers when routinely assessing feed ingredient quality.

Analysis of grain contaminants

To fully define nutritional quality, an assessment of chemical and physical contaminants in addition to potential nutrient contributions is required. To date, our ability to complete some of these analyses is limited, however, recent and current research will assist completion of these assessments in the future.

Analysis of chemical contaminants

The incidence of chemical contamination of grains used in livestock feeds is comparatively low, but the level of end–user concern is high. Grain and milling offals have a higher potential for chemical contamination, and hence closer scrutiny of these products is required (van Barneveld 1999a). Current methods of analysis for chemical contaminants of grains are very slow and prohibitively expensive. There is a need for a rapid method of screening chemical contaminants of grains. The BECAN Consulting Group (1999) developed the

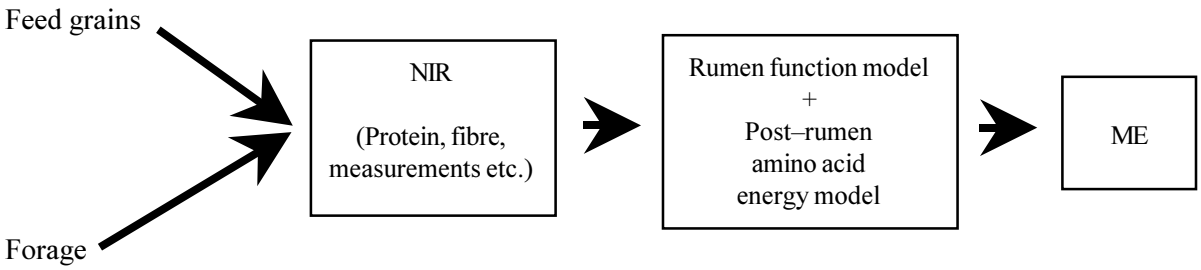

Figure 2 Schematic diagram outlining the possible role of NIRS in the prediction of nutritional quality (e.g. metabolisable energy) of feed grains for ruminants.

following priorities for chemicals to be included in residue management strategies based on a risk ranking for individual chemicals (SP, synthetic pyrethroid; OC, organochlorine; OP, organophosphate; C, carbamate):

Highest priority:

Bifenthrin (SP), Chlorpyrifos–methyl (OP), Deltamethrin (SP), Endosulfan (OC), Fenitrothion (OP).

Second highest priority:

Beta cyfluthrin (SP), Chlorpyrifos (OP), Cypermethrin (SP).

Third highest priority:

Bioresmethrin (SP), Carbaryl (C), Esfenvalerate (SP), Maldison (OP), Methoprene (N/A), S–Methoprene (N/A).

Potential exists for the development of multi–screen ELISA assays for synthetic pyrethroids, organochlorines, carbamates and methoprenes in addition to persistent organochlorines such as DDT and DDE. Biological testing techniques are required for the rapid analysis of organophosphates.

Analysis of moulds and mycotoxins

The volume of research and literature available on the effects of mould and mycotoxin contamination of grain on livestock production, and techniques available for the measurement of moulds and mycotoxins, far exceeds the potential risk these contaminants pose to the livestock industries in Australia (van Barneveld 1999a). In addition, the effects of moulds and mycotoxins are rarely widespread, with many accounts in the literature referring to a small number of animals on individual enterprises.

The National Agricultural Commodity Marketers Association of Australia (NACMA 1994) have listed the presence of moulds and mycotoxins at a 'nil' acceptance level in feed grains. That is, grains contaminated with a mould or mycotoxin should not be purchased. On this basis, only a qualitative measure of these compounds is required. Some test kits available for this type of analysis are presented in Table 3 (J. Skerritt, CSIRO Plant Industry, unpublished data).

Analysis of weed seeds and natural toxins

Contamination of feed grains with weed seeds presents a major hazard to the Australian livestock industry, and yet the procedures for rapid screening and identification of weed seeds and their toxins are limited. Two levels of measurement are required for weed contaminants of feed grains. Qualitative measurements are required for weed seeds such as heliotrope, crotolaria, mustards (*Sinapsis* sp.), common tares, *Senecio* sp. (ragwort, fireweed) and *Amsinckia* sp. which prevent the acceptance of feed grains for use in livestock diets when they are present (van Barneveld 1999a). Quantitative measurements are required for weeds like saffron, variegated thistle, Australian and hoary cress, bindweed, double gee, mexican poppy, wild radish, thornapple and burrs. The presence of these seeds is acceptable, but the levels of contamination will dictate the potential for use of the feed grain. Image analysis, a computerised form of visual examination without subjectivity, holds

Table 3 A selection of commercial field tests available for the analysis of mycotoxins (J. Skerritt, CSIRO Plant Industry, unpublished data).

Kit name	Analytes	Format	Read out	Test time
Neogen 'Agriscreen'	Aflatoxins	Microwell ELISA	Colour change	10 min
International Diagnostic Systems 'AccuCup'	Aflatoxins Zearalanone	Cup ELISA	Colour change	10 min
Vicam	Aflatoxins Ochratoxin	Affinity column*	Fluorometry	20 min
Rhone Poulenc 'Aflatest'	Aflatoxins	Affinity column	Fluorescent card or fluorometry	15 min
diAGnostix Inc 'EZ–Screen'	Aflatoxins Ochratoxins T–2 toxin Zearalanone	Card ELISA	Visual (colour change)	10 min
IDEXX 'Cite'	Aflatoxins	Cup ELISA	Visual (colour change)	10 min

*Concentrates toxin

potential for the quantitative identification of weed seeds in grain samples.

In addition to measurements for the presence of weed seeds *per se*, quantitative measures are required for toxic compounds such as pyrrolizidine alkaloids, glucosinolates, canavanine and vicine. Pyrrolizidine alkaloids are of particular concern as the levels of this toxin are poorly correlated with the number of weed seeds present and vice versa. Cargill and Slade (1996) reported that visual counts for seeds such as heliotrope which contain pyrrolizidine alkaloids tend to underestimate the level of contamination, while immuno–assay methods (e.g. ELISA) to test for the presence of the alkaloids themselves may over–estimate the degree of contamination. This statement is supported by a study involving the addition of 25 heliotrope seeds to a clean sample of wheat which was then analysed for pyrrolizidine alkaloids. The estimated number of seeds was 33.8 based on the pyrrolizidine alkaloid content. However, when the number of seeds present in a contaminated grain sample were counted visually and then estimated by analysis, the results were 23 seeds by visual count and 11.7 seeds by estimation from chemical analysis.

Economics of feed ingredient assessment

While it is easy to outline the processes required to improve characterisation of feed ingredients prior to inclusion in mixed livestock feeds, consideration must also be given to the cost–benefits of conducting such extensive analyses.

Van Barneveld (1998b) demonstrated that overestimation of the DE content of barley by 1–2 MJ/kg can result in a reduction in piggery profits of more than $4.00 per pig sold with this reduction in profits largely due to increases in daily feed intake. This simple example based on variation in a single ingredient suggests that the costs of not defining the DE content of feed ingredients could be at least $1/tonne of mixed feed in lost production alone. Further, it has been frequently demonstrated that variation in the DE content of grains of 1–2 MJ/kg could be worth as much as $15–30/tonne when formulating diets (A.C. Edwards, personal communication). On these estimates alone, routine testing of feed ingredients for parameters such as digestible energy are likely to be cost–effective if rapid technologies such as NIRS are employed.

Attempts have been made to define the cost–benefits of testing feed ingredients for contaminants (BECAN Consulting Group 1999). It was suggested that compulsory grain contaminant tests are worthwhile up to around $2/tonne, or about $50–75 a truck load, with a number of basic assumptions and based on a risk to the meat and dairy industries of $13–16 million per year. Under the assumption that feed grain prices are set in the international market, the supply of feed grain by the Australian industry is not expected to change. Assuming the consuming animal industries bear the cost of the tests, it was also suggested that there will be a reduction of 2%, 1.1% and 0.3% in Australian grown pig, poultry and beef meat, respectively. A sensitivity analysis on the basic assumptions indicated that the price of tests was strongly influenced by industry risk, delays caused by the tests at the delivery terminals, the incidence of grain rejection and particularly the average size of delivery loads. Given that it is unlikely that a suite of tests for moulds, mycotoxins, chemicals, insects and weed seed will be able to be developed within this cost constraint, strategic selection of analysis for contaminants may be required based on the source of the ingredient and the prevailing seasonal conditions.

Conclusions

Adoption of existing technology and documented protocols could improve our ability to assess livestock feed ingredient quality. Based on the above discussion, the following could form a base ingredient assessment protocol in a commercial feed production system:

Employ sampling procedures sufficient for the analysis of chemical residues, weed seeds, natural toxins, insects and nutritional quality for every feed ingredient accepted at the point of feed manufacture. Attention should be directed towards sampling methods, sampling frequency, sample size, sample storage and sample analysis.

- Utilise NIRS technology for the assessment of nutritional quality of grains for pigs, particularly available energy contributions. Technology for the assessment of nutritional quality for poultry and ruminants requires further refinement. If chemical parameters are to be measured, analysis of non–starch polysaccharides and fibre components should take preference.
- Analysis of ingredients for chemical residues and plant toxins should become routine when ELISA based test kits become available.
- Analysis of ingredients for moulds and mycotoxins should be completed strategically using existing ELISA based test kits depending on the source of the sample and the prevailing seasonal conditions.
- Cost benefits of conducting specific analysis should be clearly defined before finalising a livestock feed ingredient assessment protocol.

References

Anon (1998). Effects of sampling size, method limited in barley DON study. *Premium Grains* 15 September/October, 1998.

Batterham, E.S., Lewis, C.E., Lowe, R.F., and McMillan, T. L.C.J. (1980). Digestible energy content of cereals and wheat by–products for growing pigs. *Animal Production* **31**, 259–271.

BECAN Consulting Group (1999). Contaminants in Premium Livestock Grains—Preliminary Report on Chemical Residues in Premium Livestock Grains. Grains Research and Development Corporation: Canberra.

Black, J.L., Campbell, R.G., Williams, I.H., James, K.J. and Davies, G.T. (1986). Simulation of energy and amino acid utilization in the pig. *Research and Development in Agriculture* **3**, 121–145.

Canadian Grain Commission (1999). Taking a representative sample. *Commission Facts.* Canadian Grain Commission, Winnipeg.

Cargill, C.F. and Slade, J. (1996). *Problems Associated with Feeding Grain Contaminated with Heliotrope Seeds to Pigs.* Pig Research and Development Corporation, Canberra.

Chelkowski, J., Golinski, P., Radomyska, W., and Wiewiorowska, M. (1983). Occurrence of zearalenone and fungi producing it in feedstuff components. *Medycyna Weterynaryjna* **39**, 481–482.

Flinn, P.C. and Downes, G.J. (1996). The importance of near infrared spectroscopy in deciding appropriate feeding strategies for Australian livestock. In *Near Infrared Spectroscopy: The Future Waves,* pp. 512–518 (eds. A.M.C. Davies and P. Williams). NIR Publications, Cheshire, UK.

Hellevang, K.J., Backer, L.F. and Maher, G.G. (1992). Grain stream sampling and sampler construction. *North Dakota State University Extension Service Bulletin AE–1044.*

Howell, M., Moss, M.O. and Frank, M. (1984). Distribution of mycotoxins in animal feed raw materials. *Proceedings of the 5th Meeting on Mycotoxins in Animal and Human Health, Edinburgh.*

Leeson, S. and Valdes, E.V. (1996). The prediction of metabolizable energy by near infra red analysis and in vitro techniques. Australian Poultry Science Symposium, pp. 39–45. University of Sydney, Australia.

Morgan, M.R.A. (1995). Monitoring safety of plant foods: Immunodiagnostics for mycotoxins and other bioactive compounds. In: *New Diagnostics in Crop Sciences* (eds. J.H.Skerritt and R. Appels). CAB International, Wallingford.

Morgan, C.A. and Whittemore, C.T. (1982). Energy evaluation of feeds and compounded diets for pigs; a review. *Animal Feed Science and Technology* **7**, 387–400.

National Agricultural Commodity Marketers Association of Australia (1994). *Agricultural Commodity Standards Manual.* National Agricultural Commodity Marketers Association Incorporated: Wilberforce.

Osborne, B.G., Fearn, T. and Hindle, P.H. (1993). *Practical NIR Spectroscopy With Applications In Food And Beverage Analysis.* Second Edition. Longmans Scientific and Technical, Harlow, UK.

Richardson, C.R. (1995). Current good manufacturing practices. In: *Proceedings of the Feed Manufacturing Shortcourse.* Texas Technical University, Lubbock, Texas.

van Barneveld, R.J. (1998a). Use of near infra–red spectroscopy to predict the energy content of feed grains. In: *Proceedings of the 19th Western Nutrition Conference.* Saskatoon, Saskatchewan, Canada.

van Barneveld, R.J. (1998b). Coping with limited feed resources and variable feed quality: What is the cost and what are the solutions? In: *Meeting the Challenges of Intensive Animal Production in the Next Millennium.* Kemin Asia Pty. Ltd, Singapore.

van Barneveld, R.J. (1999a). Physical and chemical contaminants in grains used in livestock feeds. *Australian Journal of Agricultural Research* (in press).

van Barneveld, R.J. (1999b). Chemical and Physical Characteristics of Grains that are Related to Variability in Energy and Amino Acid Availability in Pigs; a review. *Australian Journal of Agricultural Research* (in press).

van Barneveld, R.J., Nuttall, J.S., Flinn, P.C and Osborne, B.C. (1999). NIR reflectance measurement of the digestible energy content of cereals for growing pigs. *Journal of Near Infra–Red Spectroscopy* **7**, 1–7.

Windham, W.R., Flinn, P.C. and Johnson, R.J. (1994). Measurement of metabolisable energy for poultry feedstuffs by NIR spectroscopy. *9th European Poultry Symposium*, UK, pp. 100–104.

Wrigley, C.W. (1999). Potential methodologies and strategies for the rapid assessment of feed grain quality. *Australian Journal of Agricultural Research* (in press).

Yin, Y.L., Huang, R.L., Zhang, H.Y., Chen, C.M., Li, T.J., and Pan, Y.F. (1993). Nutritive value of feedstuffs and diets for pigs: 1. Chemical composition, apparent ileal and faecal digestibilities. *Animal Feed Science and Technology* **44**, 1–27.