# Contaminants and toxins in animal feeds

**J.P.F. D'Mello**
Scottish Agricultural College (SAC) in Edinburgh
United Kingdom

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In global terms, animal feeds and forages contain a wide range of contaminants and toxins arising from anthropogenic and natural sources. In this article, the distribution of heavy metals, radionuclides, mycotoxins, plant toxins, antibiotics and microbial pathogens in cereals, complete feeds and forages is reviewed. The impacts on farm livestock productivity and on the safety of resulting edible products are also considered. Evidence is provided to demonstrate that feeds contain a variety of substances as co-contaminants and that there are regional differences in the nature of the compounds involved. It is concluded that the options for remedial action are limited. Furthermore, although many developing countries lack appropriate legislation, change in this respect is inevitable as regulatory controls for feeds imported into Europe and America are strengthened.

## 1. INTRODUCTION

Animal feeds are routinely subject to contamination from diverse sources, including environmental pollution and activities of insects and microbes. Animal feeds may also contain endogenous toxins arising principally from specific primary and secondary substances produced by fodder plants. Thus, feed toxins include compounds of both plant and microbial origin. Although these toxins are often considered separately, because of their different origins, they share several common underlying features. Thus, particular compounds within both plant and microbial toxins may exert antinutritional effects or reduce reproductive performance in farm animals. Furthermore, the combined effects may be the result of additive or synergistic interactions between the two groups of compounds. The extent and impact of these interactions in practical livestock feeding remain to be quantified. Feed contaminants and toxins occur on a global scale but there are distinct geographical differences in the relative impact of individual compounds. The term "feed" is generally used in its widest context to include compound blends of straight ingredients as well as forages. With such a broad perspective, it is necessary and more instructive to introduce some focus. Consequently, this article is limited to a review of those contaminants and toxins that represent significant risks to farm livestock. Feed contamination arising from insect fragments and excreta will not be addressed, but the role of such vectors in the transmission of fungal spores and hyphae should not be ignored. Legal control of certain feed contaminants and toxins is in place and operating within a continually evolving framework; the salient issues will be briefly reviewed here.

## 2. ENVIRONMENTAL CONTAMINANTS

A wide range of organic and inorganic compounds may occur in feedstuffs, including pesticides, industrial pollutants, radionuclides and heavy metals. Pesticides that may contaminate feeds originate from most of the major groups, including organochlorine, organophosphate and pyrethroid compounds (van Barneveld, 1999). A recent survey indicated that 21 percent of feeds in the United Kingdom contain pesticide residues. Pirimiphos-methyl, an insecticide used in grain stores, was detected with the highest frequency. Although pesticides are potentially toxic to farm livestock, the primary focus of concern centres on residues in animal products destined for human consumption. Dioxins and polychlorinated biphenyls (PCBs) are examples of industrial pollutants that may contaminate feeds, particularly herbage. Cows grazing pastures that are close to industrial areas produce milk with higher dioxin content than cows from rural farms. In 1999, dioxin-contaminated animal fat was inadvertently added to animal feeds destined for Belgian, French and Netherlands farms. Unacceptable levels of dioxins were found in meat products and eggs from these farms.

Human health considerations are also paramount in the monitoring of radionuclide pollution. Following the Chernobyl accident in 1986, caesium-134 and caesium-137 were released, causing widespread contamination of pastures and conserved forages. As a consequence, milk and sheep carcasses became contaminated and restrictions were imposed on the movement and slaughter of sheep (MAFF, 1994).

Contamination of feeds and herbage with cadmium may occur as a result of applying certain types of fertilizers to crops and pastures. On the other hand, lead contamination arises from industrial and urban pollution, while mercury in feeds arises from the use of fishmeal.

## 3. BACTERIAL CONTAMINANTS

There is currently considerable interest in the occurrence of *Escherichia coli* in animal feeds following the association of the O157 type of these bacteria with human illness. In a recent United States study (Lynn *et al.*, 1998), 30 percent of cattle feed samples obtained from commercial sources and farms contained *E. coli*, although none of the tests for *E. coli* O157 were positive. Replication of faecal *E. coli*, including the O157 type, was demonstrated in a variety of feeds under conditions likely to occur on cattle farms in the summer months. Since faecal contamination of feeds is widespread on farms, it is an important route for exposure of cattle to *E. coli* and other organisms. The potential for exposure to bacteria also exists when poultry litters are fed to cattle (in California, for example, two such poultry waste products are commercially available for use as cattle feed). However, providing the products are adequately heat-processed prior to distribution, the risks of contamination with *E. coli*, *Salmonella* spp. and *Campylobacter* spp. are likely to be minimized or even eliminated (Jeffrey *et al.*, 1998). Nevertheless, it is worth noting that *S. enterica* commonly occurs in cattle feeds in the United States, Europe and South Africa, with contamination rates ranging from 5 to 19 percent (Krytenburg *et al.*, 1998).

*Listeria monocytogenes* tends to occur in poor-quality silages and big-bale silage. When grass is ensiled under anaerobic conditions, the low pH regime ensures that *Listeria* is excluded from the resulting silage. However, in big-bale silage a degree of aerobic fermentation may occur, raising pH levels and allowing the growth of *Listeria*. These bacteria also survive at low temperatures and in silages with high levels of dry matter. Contamination of silage with *Listeria* is important as it causes abortion, meningitis, encephalitis and septicaemia in animals and humans. The incidence of various forms of listeriosis has been increasing in recent years.

## 4. FUNGAL CONTAMINANTS

There are consistent reports of worldwide contamination of feeds with fungi and their spores. In the tropics, *Aspergillus* is the predominant genus in dairy and other feeds (Dhand, Joshi and Jand, 1998). Other species include *Penicillium, Fusarium* and *Alternaria*, which are also important contaminants of cereal grains (D'Mello, Macdonald and Cochrane, 1993). Fungal contamination is undesirable because of the potential for mycotoxin production (see next section). However, spores from mouldy hay, silage, brewers' grain and sugar-beet pulp may be inhaled or consumed by animals with deleterious effects termed "mycosis". Common examples of such conditions include ringworm and mycotic abortion. The latter may occur in cattle as a result of systemic transmission and subsequent proliferation in placental and foetal tissues.

## 5. MYCOTOXINS

Mycotoxins are those secondary metabolites of fungi that have the capacity to impair animal health and productivity (D'Mello and Macdonald, 1998). The diverse effects precipitated by these compounds are conventionally considered under the generic term "mycotoxicosis", and include distinct syndromes as well as non-specific conditions. A list of the principal mycotoxins occurring in feeds and forages is given in Table 1, which also indicates the fungal species associated with the production of these contaminants. Mycotoxin contamination of forages and cereals frequently occurs in the field following infection of plants with particular pathogenic fungi or with symbiotic endophytes. Contamination may also occur during processing and storage of harvested products and feed whenever environmental conditions are appropriate for spoilage fungi. Moisture content and ambient temperature are key determinants of fungal colonization and mycotoxin production. It is conventional to subdivide toxigenic fungi into "field" (or plant-pathogenic) and "storage" (or saprophytic/spoilage) organisms. *Claviceps, Neotyphodium, Fusarium* and *Alternaria* are classical representatives of field fungi while *Aspergillus* and *Penicillium* exemplify storage organisms. Mycotoxigenic species may be further distinguished on the basis of geographical prevalence, reflecting specific environmental requirements for growth and secondary metabolism. Thus, *Aspergillus flavus, A. parasiticus* and *A. ochraceus* readily proliferate under warm, humid conditions, while *Penicillium expansum* and *P. verrucosum* are essentially temperate fungi. Consequently, the *Aspergillus* mycotoxins predominate in plant products emanating from the tropics and other warm regions, while the *Penicillium* mycotoxins occur widely in temperate foods, particularly cereal grains. *Fusarium* fungi are more ubiquitous, but even this genus contains toxigenic species that are almost exclusively associated with cereals from warm countries.

An emerging feature is the co-production of two or more mycotoxins by the same species of fungus (Table 1). This observation has enabled a fresh interpretation of the causes of well-known cases recorded in the history of mycotoxicoses.

TABLE 1
**Origin of principal mycotoxins occurring in common feeds and forage**

| Mycotoxins | Fungal species |
|---|---|
| Aflatoxins | *Aspergillus flavus; A. parasiticus* |
| Cyclopiazonic acid | *A. flavus* |
| Ochratoxin A | *A. ochraceus; Penicillium viridicatum; P. cyclopium* |
| Citrinin | *P. citrinum; P. expansum* |
| Patulin | *P. expansum* |
| Citreoviridin | *P. citreo-viride* |
| Deoxynivalenol | *Fusarium culmorum; F. graminearum* |
| T-2 toxin | *F. sporotrichioides; F. poae* |
| Diacetoxyscirpenol | *F. sporotrichioides; F. graminearum; F. poae* |
| Zearalenone | *F. culmorum; F. graminearum; F. sporotrichioides* |
| Fumonisins; moniliformin; fusaric acid | *F. moniliforme* |
| Tenuazonic acid; alternariol; alternariol methyl ether; altenuene | *Alternaria alternata* |
| Ergopeptine alkaloids | *Neotyphodium coenophialum* |
| Lolitrem alkaloids | *N. lolii* |
| Ergot alkaloids | *Claviceps purpurea* |
| Phomopsins | *Phomopsis leptostromiformis* |
| Sporidesmin A | *Pithomyces chartarum* |

## Aflatoxins

This group includes aflatoxin B1, B2, G1 and G2 (AFB1, AFB2, AFG1 and AFG2, respectively). In addition, aflatoxin M1 (AFM1) has been identified in the milk of dairy cows consuming AFB1-contaminated feeds. The aflatoxigenic *Aspergilli* are generally regarded as storage fungi, proliferating under conditions of relatively high moisture/humidity and temperature. Aflatoxin contamination is, therefore, almost exclusively confined to tropical feeds such as oilseed by-products derived from groundnuts, cottonseed and palm kernel. Aflatoxin contamination of maize is also an important problem in warm humid regions where *A. flavus* may infect the crop prior to harvest and remain viable during storage.

Surveillance of animal feeds for aflatoxins is an ongoing issue, owing to their diverse forms of toxicity and also because of legislation in developed countries (D'Mello and Macdonald, 1998). In the United

Kingdom, analysis conducted during the 1987-1990 period indicated that all imported feedstuffs complied with legislation in force for AFB1 levels. Elsewhere, however, aflatoxin levels in certain feeds still pose serious risks to animal health. Thus, in India total aflatoxin levels of 3 700 _g/kg were detected in a sample of groundnut cake. Of potentially greater significance is the contamination of maize samples in China and northern Viet Nam with combinations of AFB1 and *Fusarium* mycotoxins. In China, 85 percent of maize samples were contaminated with both AFB1 and fumonisin B1 at levels ranging from 8 to 68_g/kg and 160 to 25 970_g/kg, respectively. Feed-grade maize in northern Viet Nam had AFB1 levels ranging from 9 to 96 _g/kg, and fumonisin B1 levels in the range of 271 to 3 447 g/kg (Placinta, D'Mello and Macdonald, 1999). Between 1988 and 1989, analyses of farmgate milk in the United Kingdom showed low levels of AFM1 contamination, but more than 50 percent of milk samples in the United Republic of Tanzania were found to contain the mycotoxin (D'Mello and Macdonald, 1998). The importance of aflatoxins in animal health emerged in 1960, following an incident in the United Kingdom in which 100 000 turkey poults died from acute necrosis of the liver and hyperplasia of the bile duct ("turkey X disease"), attributed to the consumption of groundnuts infected with *Aspergillus flavus*. This event marked a defining point in the history of mycotoxicoses, leading to the discovery of the aflatoxins. Subsequent studies showed that aflatoxins are acutely toxic to ducklings, but ruminants are more resistant. However, the major impetus arose from epidemiological evidence linking chronic aflatoxin exposure with the incidence of cancer in humans.

### Ochratoxins

The *Aspergillus* genus includes a species (*A. ochraceus*) that produces ochratoxins, a property it shares with at least two *Penicillium* species. Ochratoxin A (OA) and ochratoxin B are two forms that occur naturally as contaminants, with OA being more ubiquitous, occurring predominantly in cereal grains and in the tissues of animals reared on contaminated feed. Another mycotoxin, citrinin, often co-occurs with ochratoxin. In recent Bulgarian wheat samples, OA and citrinin levels ranged from < 0.5 to 39_g/kg and from < 5 to 420_g/kg, respectively. In oats, higher levels of OA were detected (maximizing at 140_g/kg) while citrinin was below detection limits (D'Mello, 2001).

The ochratoxins and citrinin are nephrotoxic to a wide range of animal species. OA is frequently implicated in porcine nephropathy and in Balkan endemic nephropathy of humans. The role of citrinin in these syndromes has yet to be elucidated.

### *Fusarium* mycotoxins

Extensive data now exist to indicate the global scale of contamination of cereal grains and animal feed with *Fusarium* mycotoxins (D'Mello and Macdonald, 1998). Of particular importance are the trichothecenes, zearalenone (ZEN) and the fumonisins. The trichothecenes are subdivided into four basic groups, with types A and B being the most important. Type A trichothecenes include T-2 toxin, HT-2 toxin, neosolaniol and diacetoxyscirpenol (DAS). Type B trichothecenes include deoxynivalenol (DON, also known as vomitoxin), nivalenol and fusarenon-X. The production of the two types of trichothecenes is characteristic for a particular *Fusarium* species. However, a common feature of the secondary metabolism of these fungi is their ability to synthesize ZEN which, consequently, occurs as a co-contaminant with certain trichothecenes. The fumonisins are synthesized by another distinct group of *Fusarium* species (Table 1). Three members of this group (fumonisins B1, B2 and B3) often occur together in maize.

Virtually all the toxigenic species of *Fusarium* listed in Table 1 are also major pathogens of cereal plants, causing diseases such as head blight in wheat and barley and ear rot in maize. Harvested grain from diseased crops is therefore likely to be contaminated with the appropriate mycotoxins, and this is supported by ample evidence. Surveillance of grain and animal feed for the occurrence of *Fusarium* mycotoxins has been the subject of many investigations over recent years (Tables 2 and 3). The global distribution of these mycotoxins

TABLE 2
**Global distribution of deoxynivalenol (DON), nivalenol (NIV) and zearalenone (ZEN) in cereal grains and animal feed (mg/kg)**

| Country | Cereal/feed type | DON | NIV | ZEN |
|---|---|---|---|---|
| Germany | Wheat | 0.004-20.5 | 0.003-0.032 | 0.001-8.04 |
| Poland | Wheat | 2.0-40.0 | 0.01 | 0.01-2.0 |
| | Maize kernels | 4.0-320.0 | | |
| | Maize cobs: axial stems | 9.0-927.0 | | |
| Finland | Feeds and grains | 0.007-0.3 | | 0.022-0.095 |
| | Oats | 1.3-2.6 | | |
| Norway | Wheat | 0.45-4.3 | max 0.054 | |
| | Barley | 2.2-13.33 | max 0.77 | |
| | Oats | 7.2-62.05 | max 0.67 | |
| Netherlands | Wheat | 0.020-0.231 | 0.007-0.203 | 0.002-0.174 |
| | Barley | 0.004-0.152 | 0.030-0.145 | 0.004-0.009 |
| | Oats | 0.056-0.147 | 0.017-0.039 | 0.016-0.029 |
| | Rye | 0.008-0.384 | 0.010-0.034 | 0.011 |
| South Africa | Cereals/animal feed | | 0.05-8.0 | |
| Philippines | Maize | | 0.018-0.102 | 0.059-0.505 |
| Thailand | Maize | | | 0.923 |
| Korea, Republic | Barley | 0.005-0.361 | 0.005-0.361 | |
| | Maize | mean 0.145 | mean 0.168 | |
| Viet Nam | Maize powder | 1.53-6.51 | 0.78-1.95 | |
| China | Maize | 0.49-3.10 | 0.6 | |
| Japan | Wheat | 0.03-1.28 | 0.04-1.22 | 0.002-0.025 |
| | Barley | | | 0.010-0.658 |
| | Wheat | 0.029-11.7 | 0.01-4.4 | 0.053-0.51 |
| | Barley | 61.0-71.0 | 14.0-26.0 | 11.0-15.0 |
| New Zealand | Maize | max 3.4-8.5 | max 4.4-7.0 | max 2.7-10.5 |
| USA | Wheat | up to 9.3 | | |
| | Wheat (winter), 1991 | < 0.1-4.9 | | |
| | Wheat (spring), 1991 | < 0.1-0.9 | | |
| | Wheat, 1993 | < 0.5-18.0 | | |
| | Barley, 1993 | < 0.5-26.0 | | |
| Canada | Wheat (hard) | 0.01-10.5 | | |
| | Wheat (soft, winter) | 0.01-5.67 | | |
| | Wheat (soft, spring) | 0.01-1.51 | | |
| | Maize | 0.02-4.09 | | |
| | Animal feeds | 0.013-0.2 | 0.065-0.311 | |
| Argentina | Wheat | 0.10-9.25 | | |

*Source:* Adapted from Placinta, D'Mello and Macdonald, 1999.

TABLE 3
**Worldwide contamination of maize and animal feeds with fumonisins (g/kg)**

| Country | FB1 | FB2 | FB3 | Total |
|---|---|---|---|---|
| Maize | | | | |
| Benin | nd1-2 630 | nd-680 | | nd-3 310 |
| Botswana | 35-255 | nd-75 | nd-30 | 35-305 |
| Mozambique | 240-295 | 75-110 | 25-50 | 340-395 |
| South Africa | 60-70 | nd | nd | 60-70 |
| South Africa | max 2 000 | | | |
| Malawi | nd-115 | nd-30 | nd | nd-135 |
| Zambia | 20-1 420 | nd-290 | | 20-1 710 |
| Zimbabwe | 55-1 910 | nd-620 | nd-205 | 55-2 735 |
| Tanzania, United Republic | nd-160 | nd-60 | nd | nd-225 |
| Honduras | 68-6 555 | | | |
| Argentina | 85-8 791 | nd-11 300 | nd-3 537 | 85-16 760 |
| Uruguay | nd-3 688 | | | |
| Costa Rica | 1 700-4 780 | | | |
| Italy | 10-2 330 | nd-520 | | 10-2 850 |
| Portugal | 90-3 370 | nd-1 080 | | 90-4 450 |
| Viet Nam | 268-1 516 | 155-401 | 101-268 | 524-2 185 |
| China | 160-25 970 | 160-6 770 | 110-4 130 | 430-36 870 |
| Philippines | 57-1 820 | 58-1 210 | | |
| Thailand | 63-18 800 | 50-1 400 | | |
| Indonesia | 226-1 780 | 231-556 | | |
| Animal feed | | | | |
| South Africa | 4 000-11 000 | | | |
| Uruguay | 256-6 342 | | | |
| India | 20-260 | | | |

1nd = not detectable.
*Source*: Adapted from Placinta, D'Mello and Macdonald, 1999.

is a salient feature, but striking regional differences should also be noted. Another aspect worthy of comment is consistent evidence of the co-occurrence of various *Fusarium* mycotoxins in the same sample. These issues have been considered at greater length by Placinta, D'Mello and Macdonald (1999) who, for example, referred to a German study in which 94 percent of wheat samples analysed were contaminated by between two and six *Fusarium* mycotoxins and 20 percent of the samples were co-contaminated with DON and ZEN (Table 2). The most frequent combination included

DON, 3-ADON and ZEN. T-2 and HT-2 toxins were detected at levels ranging from 0.003 to 0.250 mg/kg and 0.003 to 0.020 mg/kg, respectively, but these mycotoxins only occurred in combination with DON, NIV and ZEN.

In the Lublin region of southeastern Poland, type A trichothecene contamination of barley grain was linked with the natural incidence of *Fusarium* head blight, in which the predominating organism was *F. sporotrichioides* (Placinta, D'Mello and Macdonald, 1999). Of 24 barley grain samples, 50 percent were positive for T-2 toxin, with a range of 0.02 to 2.4 mg/kg. In five of these samples, co-contamination with HT-2 toxin occurred, with a range of 0.01 to 0.37 mg/kg. Maize ears may also become naturally infected with *Fusarium* pathogens. The findings of one study in Poland indicated that infection with *F. graminearum* can result in contamination of cobs with DON (Table 2) and 15-ADON simultaneously (Placinta, D'Mello and Macdonald, 1999). Concentrations of DON and 15-ADON in Fusarium-damaged kernels ranged from 4 to 320 mg/kg and 3 to 86 mg/kg, respectively, but the axial stems of the cobs were more heavily contaminated, at 9 to 927 mg/kg (Table 2) and 6 to 606 mg/kg, respectively. Oat grains produced in Norway by commercial growers were found to be more heavily contaminated with DON than barley or wheat kernels (Table 2). In addition to NIV (Table 2), other contaminants included 3-ADON and fusarenon-X. For example, 56 percent of certain oat samples contained detectable quantities of 3-ADON at 0.03 mg/kg or more. Other notable examples of DON contamination include wheat and barley samples from Japan and the United States (Table 2). It should be stated, however, that even in samples with lower levels of contamination, high incidence rates have been recorded. Thus, 90 and 79 percent of cereal samples in the Netherlands were positive for DON and NIV respectively (Placinta, D'Mello and Macdonald, 1999).

Widespread contamination of maize and animal feed with fumonisins has recently been reported (Table 3). In most instances the predominant fumonisin was FB1. The highest values for FB1 were recorded from maize samples in China, where AFB1 co-occurred in

85 percent of samples, and in Thailand. Multiple contamination of maize with fumonisins, DON, NIV and AFB1 was also observed in northern Viet Nam. For FB2, the highest values in maize were found in samples from Argentina. In the Philippines, Thailand and Indonesia, FB1 and FB2 occurred in more than 50 percent of maize samples, and these mycotoxins co-occurred with aflatoxins in 48 percent of samples (Placinta, D'Mello and Macdonald, 1999).

The *Fusarium* mycotoxins induce a wide range of effects in farm livestock (D'Mello, 2000). DON is a potent feed intake inhibitor in pigs; ZEN is associated with reproductive abnormalities in pigs and ruminants. Fumonisins have been linked with specific syndromes, namely porcine pulmonary oedema and equine leukoencephalomalacia. Fumonisin contamination of maize in South Africa has been correlated with the occurrence of oesophageal cancer in humans.

### Endophyte alkaloids

The endophytic fungus *Neotyphodium coenophialum* occurs in close association with perennial tall fescue, while another related fungus, *N. lolii*, may be present in perennial ryegrass (D'Mello, 2000). Ergopeptine alkaloids, mainly ergovaline, occur in *N. coenophialum*-infected tall fescue, while the indole isoprenoid lolitrem alkaloids, particularly lolitrem B, are found in *N. lolii*-infected perennial ryegrass. The ergopeptine alkaloids reduce growth, reproductive performance and milk production in cattle, while the lolitrem compounds induce neurological effects in ruminants.

### Phomopsins

In Australia, lupin stubble is valued as fodder for sheep, but infection with the fungus *Phomopsis leptostromiformis* is a major limiting factor because of toxicity arising from the production of phomopsins by the fungus. Mature or senescing parts of the plant, including stems, pods and seeds, are particularly prone to infection. Phomopsin A is considered to be the primary toxin, causing effects such as illthrift, liver damage, photosensitization and reduced reproductive performance in sheep (D'Mello and Macdonald, 1998).

### Sporidesmin

*Pithomyces chartarum* is a ubiquitous saprophyte of pastures and has the capacity to synthesize sporidesmin A, a compound causing facial eczema and liver damage in sheep.

## 6. PLANT TOXINS

Many plant components have the potential to precipitate adverse effects on the productivity of farm livestock (D'Mello, 2000). These compounds are present in the foliage and/or seeds of virtually every plant that is used in practical feeding. Typical concentrations for selected toxins are presented in Table 4. Plant toxins may be divided into a heat-labile group, comprising lectins, proteinase inhibitors and cyanogens, which are sensitive to standard processing temperatures,

TABLE 4
**Plant toxins: sources and concentrations**

| Toxin | Principal sources | Typical concentrations |
|---|---|---|
| Lectins | Jackbean | 73 units/mg protein |
| | Winged bean | 40-320 units/mg |
| | Lima beans | 59 units/mg protein |
| Trypsin inhibitors | Soybean | 88 units/mg |
| Antigenic proteins | Soybean | - |
| Cyanogens | Cassava root | 186 mg HCN/kg |
| Condensed tannins | *Acacia* spp. | 65 g/kg |
| | Lotus spp. | 30-40 g/kg |
| Quinolizidine alkaloids | Lupin | 10-20 g/kg |
| Glusosinolates | Rapeseed | 100 mmol/kg |
| Gossypol | Cottonseed | 0.6-12 g/kg (free) |
| Saponins (steroidal) | *Brachiaria decumbens; Panicum* spp. | - |
| S-methyl cysteine sulphoxide | Kale | 40-60 g/kg |
| Mimosine | *Leucaena leucocephala* | 145 g/kg (seed) |
| | | 25 g/kg (leaf) |
| Phyto-oestrogens | Clover; lucerne; soybean | - |

*Source:* Compiled from D'Mello, 1995.

and a heat-stable group including, among many others, antigenic proteins, condensed tannins, quinolizidine alkaloids, glucosinolates, gossypol, saponins, the non-protein amino acids S-methyl cysteine sulphoxide and mimosine, and phyto-oestrogens. The role of these substances as antinutritional factors has been considered at length by D'Mello (2000), but the salient points are worth reiterating.

### Lectins

Lectins are proteins capable of damaging the intestinal mucosa. In contrast to most other dietary proteins, lectins resist digestive breakdown and substantial quantities of ingested lectins may be recovered intact from the faeces of animals fed diets containing one of a number of legume seeds (D'Mello, 2000). The prime example of a lectin with potent antinutritional and toxic properties is concanavalin A, a component of the jack bean. Lectins are also present in other legume grains including the winged bean and soybean. Concanavalin A enhances the shedding of brush-border membranes and decreases villus length, thereby reducing surface area for absorption in the small intestine. With other lectins, the lamina propria of the intestine may become infiltrated with eosinophils and lymphocytes. The overall effect is reduced nutrient absorption, but immune function may also be impaired.

### Proteinase inhibitors

The proteinase inhibitors are typical examples of heat-labile factors with antinutritional activity. They constitute a unique class of proteins with the ability to react in a highly specific manner with a number of proteolytic enzymes in the digestive secretions of animals. The trypsin inhibitors of soybean (Table 4) are now well characterized (D'Mello, 1995) and are important determinants of nutritive value. Proteinase inhibitors are also present in other leguminous seeds such as field beans, winged beans, pigeon pea and cowpea. Effects in animals include reduced protein digestion and endogenous loss of amino acids, with the overall result that performance is impaired.

### Antigenic proteins

Certain storage proteins of legume seeds are capable of crossing the epithelial barrier of the intestinal mucosa to elicit adverse effects on immune function in farm animals. In the case of the soybean, the antigenic proteins have been identified as glycinin and _-conglycinin. The antigenic proteins are characterized by their resistance to denaturation by conventional thermal processing procedures and to enzyme attack in the digestive tract of mammals. The most striking effects of antigenic proteins are embodied within the "immune hypersensitivity" syndrome. This condition occurs after feeding heated soybean to sensitized calves and piglets (D'Mello, 1991). The component antigens provoke extensive local and systemic immunological reactions together with severe intestinal damage. The resulting effects include abnormalities in movement of digesta, impaired nutrient absorption and a predisposition to diarrhoea.

### Cyanogens

Cyanogens occur widely in plants and in diverse forms. In sorghum and cassava (Table 4), the predominant cyanogens are, respectively, dhurrin and linamarin. The latter compound is also present in linseed. Cyanogens are glycosides that readily yield HCN and it is this latter molecule that causes dysfunction of the central nervous system, respiratory failure and cardiac arrest (D'Mello, 2000). Metabolizable energy values for poultry tend to be lower in untreated cassava root meal, presumably because of its cyanogenic potential.

### Condensed tannins

Tannins belong to a group of phenolic compounds with a molecular weight in excess of 500 daltons. Condensed tannins (CTs) are a subset of this group and are widely distributed in leguminous forages (Table 4) and seeds and in sorghum. Cattle and sheep are sensitive to CTs, while goats are more resistant. Adverse effects may be seen in sheep when CTs, including those in lotus or in browse legumes such as *Acacia* species, comprise a significant part of their diets. Primary effects include impaired rumen function and depressed intake, wool growth and live-weight gain. However, at moderate levels (30 to 40g/kg legume dry matter), CTs may result in nutritional advantages in respect of increased bypass protein availability and bloat suppression in cattle. At higher levels (100 to 120 g CTs/kg legume dry matter), reduced gastrointestinal parasitism in lambs has been reported (D'Mello, 2000).

### Quinolizidine alkaloids

The quinolizidine alkaloids occur in lupins and include lupinine, sparteine and lupanine. Bitter cultivars contain relatively high levels of total alkaloids (Table 4) and are not suitable as animal feedstuffs because of their negative effects on intake. In addition, cattle consuming certain lupin species during pregnancy may produce calves with multiple congenital deformities.

### Glucosinolates

Glucosinolates are glycosides of particular significance in brassica forage crops such as kale (Table 4; D'Mello, 2000). Removal of glucose from glucosinolates by plant or microbial enzymes (myrosinase), results in the release of a diverse array of compounds which undergo further breakdown to yield a number of toxic metabolites. The most common breakdown products are isothiocyanates and nitriles but, depending on such conditions as pH, temperature and metallic ion concentrations, a number of other metabolites may also be produced. These products may then cause organ damage, goitrogenic effects or reduced feed intake, particularly in non-ruminant animals.

### Gossypol

Gossypol pigment occurs in cottonseed (Table 4) in free and bound forms. In whole seeds, gossypol exists essentially in the free form, but variable amounts may bind with protein during processing to yield inactive forms. Free gossypol is the toxic entity and causes organ damage, cardiac failure and death. Cottonseed meal fed to bulls can induce increased sperm abnormalities and decreased sperm production.

### Saponins

Saponins are divided into two groups: steroidal saponins, which occur as glycosides in certain pasture plants such as *Brachiaria decumbens* and *Panicum species* (Table 4); and triterpenoid saponins, which occur in soybean and alfalfa. Many hepatogenous photosensitization conditions in sheep have been attributed to the intake of forage plants containing steroidal saponins. In contrast, triterpenoid saponins from alfalfa reduce feed degradation in the rumen.

### Amino acids

A wide range of non-protein amino acids occur in the foliage and seeds of plants. Forage and root brassica crops contain S-methyl cysteine sulphoxide (SMCO), while the aromatic amino acid mimosine occurs in the foliage and seeds of the tropical legume *Leucaena leucocephala* (D'Mello, 2000). Uncontrolled feeding of brassica forage to ruminants causes organ damage with haemolytic anaemia, which is attributed to the intake of SMCO. Abrupt feeding of *Leucaena* to sheep causes shedding of fleece, reduced intake, organ damage and death. In cattle, loss of hair, excessive salivation, lethargy, weight loss and enlarged thyroids are common features of *Leucaena* toxicity.

### Phyto-oestrogens

Phyto-oestrogens are a diverse group of isoflavonoid compounds found primarily in forage and grain legumes (Table 4). In clover, formononetin is the major form of phyto-oestrogen. Phyto-oestrogens are actively metabolized in the rumen to form products that vary in their biological activity. Formononetin is converted into a more oestrogenic compound. Phyto-oestrogens have been associated with "clover disease" in sheep, which is characterized by low ovulation and conception rates (D'Mello, 2000).

## 7. WEED SEEDS

Contamination of animal feeds with weed seeds is a major problem worldwide. The impact of weed seeds arises from the toxins they contain and from their diluent effects on nutrient density of feeds. The toxins include many of those cited in the previous section, particularly alkaloids, saponins, amino acids and proteinase inhibitors. Examples of weed seeds that are controlled by legislation in various countries include those of *Datura* spp., common vetch, castor-oil plant and *Crotalaria* spp.

## 8. UNDECLARED ADDITIVES

Animal products are frequently contaminated with drug residues administered through the feed. Such feed additives may be used for disease control and the enhancement of livestock performance. Residues may also arise through contamination of animal feeds with undeclared drugs. The occurrence of these drugs is mostly due to cross-contamination in feed mills (Lynas *et al.*, 1998). For example, medicated feed residues may be retained within equipment and then contaminate subsequent batches of feed. Under these conditions, levels of contamination may be low but sufficient to cause detectable residues in animal products. Lynas *et al.* (1998) examined the extent of feed contamination with undeclared antimicrobial additives in Northern Ireland. Of 247 medicated feeds, 35 percent were found to contain undeclared antimicrobials; and of 161 unmedicated feeds, 44 percent were shown to contain antimicrobials. The contaminants most frequently identified included chlortetracycline, sulphonamides, penicillin and ionophores. Sulphadimidine in contaminated feeds was sufficient to cause violative tissue residues if consumed by animals in the finishing stages. It is possible that feed contamination with undeclared antimicrobials is a global problem warranting further investigation. Drug residues in animal products are undesirable because of human health implications concerning allergies and the development of antibiotic resistance in disease organisms.

## 9. REGULATION

It is instructive and relevant to provide a brief review of the regulatory prospects for the control of undesirable substances. Currently, regulations are most comprehensive in Europe and North America, while in developing countries statutory directives may not even exist. Thus, 50 countries, mostly in Africa, have no regulations for mycotoxin control (D'Mello and Macdonald, 1998). This situation may be changed by the new rules imposed on feeds imported into the European Union (EU) which came into force in August 1999. Non-EU feed manufacturers are now required to have representatives based in the EU who can confirm declarations concerning certain quality and safety standards for imported animal feeds.

For heavy metals and aflatoxins, distinctions in prescribed limits are generally made for straight, complete and complementary feedstuffs. Additional distinctions may apply according to the destination of feeds for a particular class of animal. For controlled pesticides, separate regulations exist for feedstuffs and for fats, with virtually no distinction for the class of animal. Of the wide variety of plant toxins, only gossypol, cyanogens and certain glucosinolates are subject to regulatory control in the EU. Special regulations apply to contamination of feeds with specific bacteria. For example, under United Kingdom regulations, positive identification of *Salmonella* in feeds must be reported to a "veterinary officer of the Minister" (HMSO, 1989).

## 10. EFFECTS OF PROCESSING

Heat processing is a common procedure in feed manufacture, conferring improved properties as regards the safety and nutritive value of animal feeds. For example, heat treatment of dried poultry litter appears to be an effective method for controlling, or even eliminating, contamination with *Salmonella*, *E. coli* and *Campylobacter* (Jeffrey *et al.*, 1998). Thermal processing is also effective for denaturing proteinase inhibitors, lectins and cyanogens. However, for antigenic proteins, more complex procedures involving the use of hot aqueous ethanol extraction is required (D'Mello, 1991).

For aflatoxin-contaminated oilseeds destined for animal feed, ammoniation appears to be the processing method of choice. The feedstuff is treated with either ammonium hydroxide or gaseous ammonia at high temperatures and pressure in commercial feed mills, or at ambient temperature and low pressure in small-scale operations in developing countries. If the ammoniation reactions are allowed to proceed to completion, the detoxification process is irreversible and aflatoxin contamination is virtually eliminated. Providing that the residual ammonia is dissipated, diets containing the decontaminated meals are readily consumed by animals without ill-effects. Depending on the efficacy of decontamination, residues of AFM1 in the milk of dairy cows are substantially reduced or absent altogether. The adverse effects of tannin-rich forages may be overcome by treatment or spraying of foliage with polyethylene glycol, but the practical application of this procedure still has to be economically evaluated.

## 11. CONCLUSIONS

Animal feed, including herbage, may be contaminated with organic and inorganic compounds as well as with particulates. Organic chemicals comprise the largest group and include plant toxins, mycotoxins, antibiotics, prion proteins and pesticides. Inorganic compounds include heavy metals and radionuclides. Particulates such as weed seeds and certain bacterial pathogens are common contaminants of feed. The effects of feed contaminants and toxins range from reduced intake to reproductive dysfunction and increased incidence of bacterial diseases. Residues transferred to edible animal products represent another reason for concern. Comprehensive legislation is in place for the control of several of these chemical compounds and pathogens in feed. However, in many developing countries, particularly in Africa, statutory control of contaminants is at best rudimentary. The scope for decontamination of feeds is limited and generally uneconomic, and prevention is the most effective practical strategy.

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