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Endogenous Toxins and Mycotoxins in Forage Grasses and Their Effects on Livestock

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ABSTRACT: Plant toxins are the chemical defenses of plants against herbivory. Grasses have relatively few intrinsic toxins, relying more on growth habit to survive defoliation and endophytic fungal toxins as chemical defenses. Forage grasses that contain intrinsic toxins include *Phalaris* spp. (tryptamine and carboline alkaloids), sorghums (cyanogenic glycosides), and tropical grasses containing oxalates and saponins. Toxic effects of these grasses include neurological damage (*Phalaris* staggers), hypoxia (sudangrass), saponin-induced photosensitization (*Brachiaria* and *Panicum* spp.), and bone demineralization (oxalate-containing grasses). Endophytic toxins in grasses include ergot alkaloids in tall fescue and tremorgens (e.g., lolitrem B) in perennial ryegrass. Lolitrems cause neurological effects, producing the ryegrass staggers syndrome. Annual ryegrass toxicosis is caused by corynetoxins, which are chemically similar to tunicamycin antibiotics. Corynetoxins are produced by *Clavibacter* bacteria that parasitize a nematode, *Anguina agrostis*, that may infect annual ryegrass. Corynetoxins inhibit glycoprotein synthesis, causing defective formation of various blood components of the reticulo-endothelial system. Another mycotoxin in ryegrass is sporidesmin, which causes liver damage and secondary photosensitization (facial eczema). *Fusarium* toxins such as zearalenone and trichotheecenes also occur in forage grasses. Kikuyugrass poisoning results in severe damage to the ruminal epithelium and omasal mucosa, and neurological signs. The causative agent, which may be associated with army worm predation of the grass, has not been identified. The properties and significance of these toxins are reviewed.

Key Words: Grasses, Endophytes, Toxins, Mycotoxins, Livestock, Herbivores

Introduction

Plants contain a tremendous array of substances that are poisonous to animals (Cheeke and Shull, 1985). For virtually every organ, tissue, and system in animals, there is, somewhere in the plant world, a chemical inhibitory or antagonistic to it. From an animal's viewpoint, these are toxins associated with plants. From the plant's viewpoint, these compounds are chemical defenses. Because plants are immobile and unable to resist herbivory by physically escaping, they must have other means of protecting themselves against being eaten. Their defenses are primarily physical and chemical. Physical defenses include spines, thorns, leaf hairs, and highly lignified tissue. Chemical defenses are substances that protect the plant by having adverse effects on herbivores. In the broad sense, herbivores are any animals, including insects and other invertebrates, as well as mammalian and avian species, that feed on plants. Microbes such as bacteria and fungi can also be regarded as herbivores. Plant chemicals that defend against many fungal and bacterial diseases are also toxic to large animals. Although the interaction between plant defenses and mammalian herbivores is the central theme of this paper, it should be recognized that most of the evolutionary pressure for development of plant toxins is exerted by microbes and insects, rather than by the herbivory of large animals. To some extent, this is less true for grasses than for herbaceous plants because of the importance of grazing animals in herbivory of grasses and grass-herbivore coevolution. In contrast to herbaceous plants, which are often rich in chemical defenses such as alkaloids, glycosides, toxic amino acids and phenolic compounds, grasses are generally not as well defended chemically. Most grasses have coevolved with grazing animals and by growth habit are able to survive frequent defoliation. Hence there are relatively few intrinsic toxins in common forage grasses. However, grasses sometimes...
contain fungal metabolites (mycotoxins) that contribute to their defense against herbivory. Frequently, this is a mutualistic relationship; the plant provides a suitable environment for the fungi and the fungi protect this environment by synthesizing protective chemicals (mycotoxins). Often the fungi live within the plant tissues, including the seeds, and depend on the plant for reproduction. Fungi living wholly within plant tissues are called endophytes.

Grass toxins can be conveniently divided into those intrinsic to the plant and those produced by endophytes or other fungi associated with the grass.

**Toxins Intrinsic to Grasses**

Examples of toxins intrinsic to various grasses include tryptamine alkaloids in *Phalaris* spp., oxalates in numerous tropical grasses, cyanogenic glycosides in forage sorghums such as sudangrass, and photosensitizing agents such as saponins in various tropical grasses. The occurrence, chemical nature, and toxicologic effects of these substances in livestock are reviewed.

**Phalaris Poisoning**

In North America, the principal *Phalaris* spp. used as livestock forage is reed canarygrass (*P. arundinacea*). It is an important forage on wet, poorly drained soils; the plant survives prolonged flooding. It is often unpalatable and supports lower animal performance than would be predicted from its nutrient content. It contains at least eight different alkaloids, including five indole alkaloids (Figure 1) and three β-carbolines. These alkaloids all contain an indole nucleus. Reed canarygrass also contains hordenine, a N-containing phenol (Figure 1). Technically, hordenine is not an alkaloid because it does not contain N in a heterocyclic ring, but it is often referred to as an alkaloid in the literature. The tryptamine and β-carboline alkaloid concentrations can be readily modified by plant selection. Marten et al. (1981) demonstrated improved animal performance with low-alkaloid cultivars. Lambs grazing the low-alkaloid cultivars did not develop the diarrhea typically seen with reed canarygrass. Marten et al. (1981) concluded that the threshold level for total indole alkaloid concentration in reed canarygrass at or above which diarrhea and reduced growth rate occurs is about 0.2% of the dry weight. Reduced animal performance and increased diarrhea incidence become progressively greater with alkaloid levels higher than 0.2%. The low palatability of reed canarygrass is associated with the hordenine content (Marten et al., 1976).

Canadian researchers (Wittenberg et al., 1992; Duynisveld and Wittenberg, 1993) have evaluated low-alkaloid reed canarygrass cultivars as forage. In general, animal performance was improved with the low-alkaloid cultivars. Environmental factors such as water stress and continuous grazing increase the gramine content of reed canarygrass (Duynisveld and Wittenberg, 1993). The alkaloid content is lower in hay than in the fresh plant but is not reduced by the ensiling process (Tosi and Wittenberg, 1993).

Reed canarygrass has not commonly been implicated in lethal toxicoses in North America but has been a cause of incoordination and death in sheep in New Zealand (Simpson et al., 1969). Other *Phalaris* spp. in the United States have caused animal mortalities. East and Higgins (1988) reported an outbreak of *Phalaris* poisoning in sheep grazing *P. aquatica* (formerly *tuberosa*) in California. Ewes developed chronic neurological signs such as head nodding and a stiff gait with muscle tremors, with varying degrees of incoordination and falling. Numerous animals died with characteristic lesions of the brain and nervous system. In some cases, development of clinical signs occurred months after exposure to *Phalaris* ceased. A similar outbreak occurred in Louisiana in sheep and cattle grazing *P. caroliniana* (Nicholson et al., 1989). Delayed development of clinical signs is characteristic of *Phalaris* staggerers (Bourke et al., 1987).

*Phalaris* poisoning has been extensively studied in Australia. Two major syndromes are encountered, a sudden death syndrome and a nervous syndrome (Bourke et al., 1990). The sudden death syndrome is characterized by sudden collapse and cardiac arrest (Bourke et al., 1988). The cause of the cardiac arrest is not known but does not seem to be associated with the tryptamine alkaloids (Kennedy et al., 1986; Bourke et al., 1988). In recent studies, Bourke and Carrigan (1992) suggested as many as four possible factors involved, including a cardiopulmonary toxin, a thiaminase and amine cosubstrate, cyanogenic compounds, and nitrate compounds. Anderton et al. (1994) have suggested that N-methyltyramine is the causative factor of cardiac arrest.

The neurologic syndrome seems to be caused by dimethylated indole amines (tryptamines) in *P. aquatica* (Bourke et al., 1990). Bourke et al. (1990) suggest that the nervous syndrome induced by *P. aquatica* results from a direct action of *Phalaris* alkaloids on serotonergic receptors in specific brain and spinal cord nuclei. Characteristic indole-like pigments are found in the brain and spinal cord in animals with *Phalaris* staggerers. These are probably post-effect metabolites of the tryptamine alkaloids (Bourke et al., 1990). Signs of toxicosis often show a delayed onset after *Phalaris* consumption has ceased.

**Oxalates in Grasses**

Various tropical grasses contain soluble oxalates (Figure 2) in sufficient concentration to induce calcium deficiency in grazing animals. These include buffelgrass (*Cenchrus ciliaris*), pangolagrass (*Digitaria decumbens*), setaria (*Setaria sphacelata*),
and kikuyugrass (*Pennisetum clandestinum*). Numerous problems have been noted with these grasses in Australia, primarily with horses. Oxalates react with calcium to produce insoluble calcium oxalate, reducing calcium absorption. This leads to a disturbance in the absorbed calcium:phosphorus ratio, resulting in mobilization of bone mineral to alleviate the hypocalcemia. Prolonged mobilization of bone mineral results in nutritional secondary hyperparathyroidism, or osteodystrophy fibrosa, in horses consuming these tropical grasses (Blaney et al., 1981a,b, 1982; McKenzie et al., 1981). Cattle and sheep are less affected because of degradation of oxalate in the rumen (Allison et al., 1981). However, cattle mortalities from oxalate poisoning due to acute hypocalcemia have occurred on setaria pastures (Jones et al., 1970) and sheep have been poisoned while grazing buffelgrass (McKenzie et al., 1988).

Levels of .5% or more soluble oxalate in forage grasses may induce nutritional hyperparathyroidism in horses. Levels of 2% or more soluble oxalate can
lead to acute toxicosis in ruminants (McKenzie et al., 1988). The oxalate content of grasses is highest under conditions of rapid growth with concentrations as high as 6% or more of dry weight.

Cyanogenic Grasses

Cyanide poisoning associated with the forage sorghums such as sudangrass is well known. Sorghums contain a cyanogenic glycoside, dhurrin, from which free cyanide can be released by enzymatic action (Figure 3). The glycoside occurs in epithelial cells of the plant, whereas the glycoside-hydrolyzing enzymes are in the mesophyll cells (Wheeler and Mulcahy, 1989). Damage to the plant from wilting, trampling, frost, drought, and so on results in the breakdown of cell structure, causing exposure of the glycoside to the inherent hydrolytic enzymes and formation of free cyanide. The cyanide potential and risk of poisoning decreases as forage sorghums mature (Wheeler et al., 1990). Nutritional value of forage sorghums also declines markedly with maturity, so a management strategy of delayed grazing to avoid toxicosis may result in poor animal performance (Wheeler and Mulcahy, 1989).

Acute cyanide toxicosis is caused by the inhibition of cytochrome oxidase, a terminal respiratory enzyme in all cells. When cytochrome oxidase is inhibited, the cells suffer from rapid ATP deprivation. Signs include labored breathing, excitement, gasping, staggering, convulsions, paralysis, and death. The blood is bright red due to its high content of oxyhemoglobin. The myocardium is the most severely affected tissue; death is caused by acute cerebral anoxia resulting from cardiac failure (Seawright, 1989).

Although cyanide is extremely toxic, acute toxicosis occurs only after detoxification processes are overwhelmed. Cyanide is readily detoxified in animal tissues by reacting with thiosulfate to form thiocyanate:

\[ \text{S}_2\text{O}_3^{2-} + \text{CN}^- \rightarrow \text{SO}_3^{2-} + \text{SCN}^- \]

This reaction is catalyzed by thiosulfate:cyanide sulfur transferase (rhodanese). The resulting thiocyanate is excreted in the urine. With chronic exposure to dietary cyanogens, chronically elevated blood thiocyanate may have physiological effects, including goitrogenicity and possible involvement in neurologic disturbances. In humans, chronic consumption of cyanogenic cassava as a staple food may lead to tropical ataxic neuropathy, characterized by lesions of optic, auditory, and peripheral nerves and elevated blood levels of thiocyanate (Cheeke and Shull, 1985). A similar condition occurs with prolonged cyanide exposure in cattle and horses, with ataxia and degenerative lesions of the central nervous system (Seawright, 1989; Wheeler and Mulcahy, 1989). Cystitis and urinary incontinence also occur in chronic cyanide exposure (Knight, 1968; McKenzie and McMicking, 1977). Although elevated blood thiocyanate is noted in these chronic conditions, a role of thiocyanate in their etiology has not been demonstrated. Sulfur deficiency induced by the increased excretion of thiocyanate in animals on sorghum pasture is common in Australia (Wheeler and Mulcahy, 1989), causing reduced feed intake and a decline in animal performance. Provision of salt containing 5% sulfur overcomes the deficiency. Caution is needed with sulfur supplementation because excessive sulfur can lead to copper deficiency, induced by ruminal formation of thiomolybdates that complex with copper and reduce its absorption.

The likelihood of acute cyanide toxicosis may be greater with sorghum hay than with grazing of the fresh plant. Dry matter may be consumed much more rapidly in the form of hay than as fresh pasture. Ground and pelleted sorghum hay may be especially toxic because of the rapid rate of intake and cyanide release (Wheeler and Mulcahy, 1989). Ensiling reduces the cyanide potential markedly (Wheeler and Mulcahy, 1989).

Cyanogens occur in other grasses such as Cynodon spp., which are tropical forage grasses (Georgiadis and McNaughton, 1988). These authors noted that defoliation of these grasses increases the cyanogen content of the new growth, suggesting that cyanide plays a role in deterring herbivory.

Photosensitizing Agents in Grasses

Photosensitization refers to the production of skin lesions caused by the interaction of sunlight with exogenous substances that are capable of being activated by solar radiation to tissue-damaging free radicals. Photosensitization is classified as either primary or secondary (hepatogenous). Primary photosensitization is caused by dietary substances that are absorbed and subsequently react with sunlight in the integument. Examples include hypericin in St. John's wort (Hypericum perforatum), fagopyrin in buckwheat (Fagopyrum esculentum), and furocoumarins in various plants including parsnips, parsley, and celery. Secondary or hepatogenous photosensitization in grazing livestock occurs as a result of liver damage. The damaged liver is unable to adequately remove a chlorophyll metabolite, phyloerythrin, from the blood for excretion in the bile. Phyloerythrin is a photodynamic agent. Thus, secondary photosensitization may occur with a wide variety of hepatotoxic agents, and it is most severe when large amounts of lush, green forage are ingested, which produces a large chlorophyll intake.

Numerous tropical and warm-season grasses cause hepatogenous photosensitization in grazing animals. These include various Panicum and Brachiaria spp. (Graydon et al., 1991; Miles et al., 1992b). Liver damage characterized by deposition of crystalline substances in and around the bile ducts is observed.
Affected animals develop photophobia and severe dermatitis. The plant factors responsible for the crystal formation are steroidal saponins (Bridges et al., 1987). New Zealand researchers (Miles et al., 1991, 1992b; Munday et al., 1993) have demonstrated that the crystalline material consists of calcium salts of steroidal saponin glucuronides. These authors caution that although the bile crystals are saponin derivatives, plant saponins are not necessarily the cause of the liver damage and photosensitization. Experimental production of photosensitization by administration of isolated saponins takes much greater quantities than would be obtained from consumption of the plants (Kellerman et al., 1991). Miles et al. (1992a) suggest that other hepatotoxins such as mycotoxins (e.g., sporidesmin) may have a synergistic effect with saponins. Interactions between saponins and other hepatotoxic agents could explain the sporadic incidence of photosensitization. Mullenax (1991) suggested that the photosensitization outbreaks seen with cattle on Brachiaria decumbens pastures may be caused by the mycotoxin sporidesmin rather than by intrinsic factors in the grass. However, Smith and Miles (1993) provide convincing evidence that steroidal saponins are the plant factor primarily involved. Sporidesmin and other hepatotoxic mycotoxins could certainly have a synergistic effect. Klein-grass (Panicum coloratum) is widely grown in Texas, where it has caused outbreaks of hepatoegenous photosensitization in sheep (Bridges et al., 1987) and horses (Cornick et al., 1988). Saponins were identified as causative agents, but the sporadic incidence of the condition suggests that other interacting factors such as mycotoxins contribute to the problem.

Extrinsic Toxins

Some of the most significant livestock toxicoses associated with forage grasses are caused by fungal toxins. The major grass-induced toxicosis in the United States is tall fescue toxicosis caused by endophytic alkaloids. Tall fescue toxicosis is discussed in detail in other papers in this symposium (Bacon, 1995; Cross, 1995; Joost, 1995; Paterson et al., 1995; Porter, 1995). Other significant toxicoses of fungal origin include perennial ryegrass staggers, facial eczema, and Fusarium-induced ill-thrift and impaired reproduction. Exogenous organisms other than fungi may also be involved. Annual ryegrass toxicosis involves a nematode-bacterium-bacteriophage complex. Kikuyugrass poisoning may involve army worm infestation. A number of these toxicoses caused by extrinsic toxins in grasses are reviewed.

Perennial Ryegrass Staggers

Perennial ryegrass staggers is a disorder of animals grazing perennial ryegrass pastures. It is characterized by neurological signs such as incoordination, staggering, head shaking, and collapse. Animals generally appear normal until disturbed. The neurological effects are temporary, and although affected animals usually regain normal composure within a short time, the condition complicates animal management practices such as moving sheep from one pasture to another. Mortality may occur from misadventure if affected animals fall over cliffs, into ditches or ponds, and so on. The disease is particularly prevalent in New Zealand but occurs in most areas where ryegrass is an important pasture species. The causative agents are compounds called tremorgens. Although a number of tremorgens have been identified, the most important is lolitrem B, produced by the endophytic fungus Acremonium lolii (DiMenna et al., 1992; Miles et al., 1992a). Staggers may also be caused by other tremorgens such as janthitrem B, produced by Penicillium spp. growing on dead plant litter in ryegrass pastures (Gallagher et al., 1977; Mantle et al., 1977; Wilkins et al., 1992). The tremorgens (Figure 4) are indole-diterpene neurotoxins (Miles et al., 1992a).

As with Acremonium infection of tall fescue, endophytes in ryegrass improve the vigor of the grass. In New Zealand, persistence of ryegrass in pastures is greatly facilitated by endophyte infection, which protects the young plant shoots (tillers) from the Argentine stem weevil. The major alkaloid with insect-deterring properties is peramine, which has low toxicity to mammals (Rowan and Gaynor, 1986). Plant breeding efforts to develop endophyte-infected
ryegrass with high insect resistance but low mammalian toxicity show promise (Fletcher, 1993).

Lolitrem B concentrations in *Acremonium lolii*-infected ryegrass plants are highest in the leaf sheaths and lowest in leaf blades (DiMenna et al., 1992). Thus, the staggers syndrome is most often seen in closely grazed pastures. Signs of ryegrass staggers develop when the lolitrem B concentrations exceed 2 to 2.5 μg/g of dry matter (DiMenna et al., 1992).

Decreased serum prolactin has been noted in lambs grazing endophyte-infected ryegrass (Fletcher and Barrell, 1984). This effect is likely caused by ergot alkaloids rather than tremorgens. The ergot alkaloids of tall fescue, such as ergovaline, have dramatic prolactin-lowering effects (Porter et al., 1990). Ergovaline is also produced by endophytes in ryegrass. However, it would be desirable to determine whether tremorgens have a specific effect on prolactin. Piper (1989) noted that serum aspartate amino transferase was elevated in sheep with ryegrass staggers, which suggests hepatobiliary damage. However, Fletcher (1993) suggested that because serum levels of aspartate amino transferase are also elevated with muscle damage, the likely cause of the changes in serum enzymes is secondary muscle damage from bruising and other physical injuries during episodes of staggers. Fletcher (1993) also reported elevated serum creatine kinase activity along with elevated aspartate amino transferase, suggesting enzyme leakage from muscle cells.

Perennial ryegrass staggers is a serious problem in New Zealand. It has been known for many years in Oregon (Shaw and Muth, 1949), where the condition has also been noted in horses fed ryegrass straw (Hunt et al., 1983). Oregon is a major grass seed-producing area, with tall fescue and perennial ryegrass the two major species grown. Endophyte-infected cultivars of both species make up an increasing share of the total seed production. These endophyte-infected varieties are used for turf (lawns, playgrounds, highway banks, etc.) because of the greater vigor of the grass. However, because the seed fields are grazed by sheep during the winter, problems with ryegrass staggers in Oregon are increasing.

Endophyte-infected forage cultivars have also been introduced into the United States from New Zealand, leading to increased incidence of staggers. These cultivars are appropriate for New Zealand because of their resistance to the Argentine stem weevil but are inappropriate for the United States, where the stem weevil does not occur. Other recent reports of ryegrass staggers involve cattle and sheep in northern California (Galey et al., 1991), fallow deer in Australia (Mitchell and McCaughan, 1992), and cattle in Argentina (Odriozola et al., 1993).

**Sleepygrass Toxicosis**

Sleepygrass (*Stipa robusta*) is a perennial bunch grass found on rangelands of the southwestern United States (Colorado, Arizona, Texas, and New Mexico). Consumption of the grass by cattle and horses causes a profound stuporous condition which may last several days. Animals may enter a state of deep somnolence from which they cannot be roused. Epstein et al. (1964) reported that diacetone alcohol present in the plant is the soporific agent. However, more recent work, reviewed by Petroski et al. (1992), suggests that ergot alkaloids (Figure 5) produced by *Acremonium* endophytes in *Stipa robusta* are the causative agents. The predominant ergot alkaloid identified in sleepygrass is lysergic acid amide, which is similar in structure to the well-known hallucinogen LSD (lysergic acid diethylamide). Petroski et al. (1992) collected sleepygrass forage near Cloudcroft, NM, a mountainous area with many reports of sleepygrass toxicity. All samples contained *Acremonium* endophyte. The plant material was extracted and a number of ergot alkaloids identified. The concentrations of lysergic acid amide and isolysergic acid amide, both of which produce pronounced sedative effects in humans, were sufficiently high to account for the effects of sleepygrass on cattle and horses (assuming that dose responses are similar to those of humans). For example, they calculated that at an expected intake of 1% of body weight of sleepygrass, horses would consume approximately six times the dose expected to produce a sedative effect in humans. Lysergic acid and
isolysergic acid amides have also been isolated from endophyte-infected tall fescue at levels approximately 10% of those in sleepygrass (Petroski et al., 1992). This would likely explain the depression and dullness sometimes noted in animals fed endophyte-infected tall fescue. Powell and Petroski (1992) have reviewed alkaloids found in endophyte-infected grasses, including sleepygrass.

**Facial Eczema**

Facial eczema is secondary photosensitization caused by the mycotoxin sporidesmin, contained in spores produced by the fungus *Pithomyces chartarum* (Smith and Embling, 1991). It is mainly of importance in New Zealand, where it is of major concern to the sheep and dairy industries. Affected animals develop severe dermatitis of light-skinned areas such as the face and udder. Productivity of affected animals is markedly impaired, including reduced fertility of sheep (Morris et al., 1991).

The hepatotoxic effects of sporidesmin are believed to be caused by the intracellular formation of free radicals that react with molecular oxygen to produce the superoxide radical (Munday and Manns, 1989). This is a powerful oxidizing agent that causes liver damage. Copper strongly catalyzes the oxidation of sporidesmin (Munday and Manns, 1989). The dietary administration of zinc and iron salts to animals protects against sporidesmin toxicsis. Zinc supplementation is routinely used for this purpose in New Zealand (Munday and Manns, 1989). These elements reduce copper absorption, thus reducing the amount of copper available in the liver to serve in a catalytic role. Zinc also binds with a sporidesmin metabolite, preventing its auto-oxidation. The report of Munday and Manns (1989) should be consulted for further information on the effects of copper, zinc, and iron on sporidesmin metabolism.

There are genetic and species differences in susceptibility to sporidesmin toxicity. For example, goats are considerably more resistant to sporidesmin than sheep (Smith and Embling, 1991). Saanen goats were more susceptible than feral and Angora goats. Selection for resistance to facial eczema has been effective in sheep (Morris et al., 1989) and dairy cattle (Morris et al., 1991) in New Zealand.

**Fusarium Toxicosis**

*Fusarium* toxins such as zearalenone and trichothecenes are common mycotoxins found in cereal grains and are important causes of mycotoxicosis in North America (Cheeke and Shull, 1985). They are not commonly associated with forage-based feeding systems. However, *Fusarium* toxins have been found to be of significance in grazing animals in New Zealand (DiMenna et al., 1987, 1991). They have been linked to impaired sheep fertility and poor growth (ill-thrift). Zearalenone at levels found in New Zealand forage impairs ewe fertility (Smith et al., 1990), whereas the trichothecenes are probably the cause of ill-thrift. Of particular concern to the New Zealand livestock industry is that zearalenone is chemically similar to the growth promotant α-zearalanol (zeranol), which is banned in some countries. The occurrence of tissue residues of natural origin could adversely affect New Zealand exports of animal products. However, techniques are available that are capable of separating zearalenone and its metabolites from zeranol and its metabolites (Richard et al., 1993).

**Kikuyugrass Poisoning**

Kikuyugrass (*Pennisetum clandestinum*) is a widely grown tropical forage grass. It may contain a number of deleterious factors, including saponins, nitrates, and oxalates. It may cause profuse ruminal foam and bloat, presumably because of the saponins. A condition of unknown etiology called kikuyu poisoning has been observed in cattle, goats, sheep, and horses.
mainly in New Zealand, Australia, and South Africa. Signs of toxicosis generally occur 24 to 48 h after animals consume the toxic pasture. Clinical signs include anorexia, depression, pilo-erection, drooling, colic, grinding of teeth, cessation of ruminal and intestinal movement, and lack of fecal excretion. Sham-drinking is a distinctive feature; animals congregate at water and attempt but fail to drink. Necrosis of the ruminal epithelium and omasal mucosa is extensive. South African researchers (Newsholme et al., 1983) noted that kikuyu poisoning of cattle occurred in association with previous army worm invasion of pastures. This association was also noted in New Zealand (Smith and Martinovich, 1973). However, in Australia, kikuyu poisoning occurs in the absence of the army worm (Wong et al., 1987; Peet et al., 1990). Newsholme et al. (1983) suggested that mycotoxins might be involved. Wong et al. (1987) found no evidence of fungal involvement, but noted that the lush grass growth following drought-breaking rains was most toxic, suggesting to them that a plant toxin is involved. In South Africa, kikuyu poisoning is associated with high nitrogen fertilization, irrigation or rain, hot weather, and rapidly growing grass (D. J. Schneider, Regional Veterinary Laboratory, Stellenbosch, South Africa, personal communication). Sheep are apparently somewhat more resistant than other livestock (Peet et al., 1990). The etiology of kikuyu poisoning is unresolved and may involve several factors.

Annual Ryegrass Toxicosis

Annual ryegrass toxicosis is a disease of livestock caused by a group of highly toxic glycolipids called corynetoxins. These toxins are very similar in chemical structure to the tunicamycin antibiotics (Jago and Culvenor, 1987); the signs and lesions of annual ryegrass toxicosis can be produced by administration of tunicamycin (Finnie and Jago, 1985). The signs of toxicosis include neurological disturbances, a high-stepping gait, incoordination, and convulsions. Although superficially similar to perennial ryegrass staggers, annual ryegrass toxicosis is a lethal condition with extensive brain damage, particularly to the cerebellum.

The production of corynetoxins involves a complex of factors, including the grass, a nematode, a bacterium, and probably a virus (McKay and Ophel, 1993). Seedlings of annual ryegrass may become infected with a nematode, *Anguina agrostis*, that can infect the plant shortly after germination. The nematode larvae crawl up the plant to the growing tip and are passively carried as the plant grows. When the grass begins to flower, the larvae burrow into the developing flower, where they become mature nematodes. The infected flower does not produce seed; the seed is replaced by a gall in which the adult nematodes lay eggs that hatch into larvae in the gall. The larvae remain dormant until the following season, when they become active in the soil and infect ryegrass seedlings. The nematode itself is nontoxic. However, if the nematodes are infected with *Clavibacter toxicus* (formerly *Corynebacterium rathayi*), corynetoxins are produced and the seed galls are toxic (Riley and Ophel, 1992). There is evidence that the toxin is produced only if the bacteria are infected with a bacteriophage (Riley and Gooden, 1991; Ophel et al., 1993).

The molecular mode of action of corynetoxins (and tunicamycins) is an inhibition of lipid-linked N-glycosylation of glycoproteins. This inhibition results in decreased N-glycosylation of a wide range of glycoproteins, which include enzymes, hormones, structural components of the cell membrane, and extracellular matrices and membrane receptors (Jago et al., 1983).

Control of annual ryegrass toxicosis involves preventing nematode infection of the grass. Crop rotation, field burning, clipping immature seed heads, and fallowing are methods of eliminating nematodes. Transport of infected plant material to non-infected areas should be avoided.

Annual ryegrass toxicosis has been a problem mainly in Australia and South Africa. Although the disease was reported many years ago in Oregon (Shaw and Muth, 1949; Galloway, 1961), it has not been observed recently because of the widespread use of open field burning to dispose of grass straw and stubble. Although annual ryegrass is the main grass involved, recent reports from Australia (Finnie, 1991; Bourke et al., 1992; McKay et al., 1993) implicate several other grasses, including *blowngass* (*Agrostis avenacea*) and annual beardgrass (*Polypogon monspeliensis*). The disorders associated with these grasses are locally known as floodplain staggers (blowngass) and Stewarts Range Syndrome (beardgrass).

Implications

Numerous livestock toxicoses are caused by natural toxins in forage grasses. Some of these toxins are produced by the grass tissues (e.g., cyanogens, tryptamine alkaloids, saponins, oxalates), whereas others such as ergot alkaloids and tremorgens are produced by endophytic fungi that have a mutualistic relationship with the host grass. Knowledge of various aspects of these toxins and toxicoses is necessary for optimal management and utilization of forage grasses.

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