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Ingestion of Toxic Plants by Livestock

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Toxins exist everywhere in nature. We define toxins as chemicals that naturally occur in plants and can cause illness or death if eaten in sufficient quantities. Toxins occur in all grasses, forbs, shrubs, and trees around the world (see Table 1). Even the vegetables we grow in our gardens contain low levels of toxins. Tomatoes and potatoes contain alkaloids, corn contains cyanogenic glycosides, and cabbage contains glucosinolates. Eating plants means dealing with toxins. Fortunately our liver and kidneys are able to detoxify and excrete most levels of toxins commonly found in the vegetables we grow and eat. In addition, few toxins are eaten in amounts large enough to cause illness or death because animals and humans can regulate their intake of toxins. Eating plants is a matter of regulating toxins rather than avoiding them.

Benefits to Plants

Toxins benefit plants because plants that quickly induce mild aversions in foragers are more likely to survive than those that do not. When toxins occur in moderate concentrations they cause livestock to limit intake of certain plants thereby spreading grazing pressure more evenly across plant communities. High concentrations of toxins in some plants, such as sagebrush, severely restrict intake. Over time, these plants high in toxins tend to dominate rangelands. Grazing gives them a competitive advantage because livestock prefer to eat other plants lower in toxins.

Variation in Toxin Structures

Within a class of different toxins, different plant species produce a variety of compounds with different chemical structures. Larkspur, for example, makes 23 different alkaloids, but only two - methyllycaconitine and 14-deacetylnudicauline - are toxic to cattle (Stegelmeier et al., 1998). Presumably, it takes little energy to make different toxins with the same basic structure, and the benefits are great. Plants that make a variety of toxins are more likely to deter feeding by many different animals. That's because different species of livestock differ in their ability to tolerate the effects of different toxins.

Table 1. Several plant species that contain toxins (Cheeke 1998).

Toxin	Plant Species
Cyanide compounds	Arrow grass, White clover, Serviceberry, Chokecherry, Sudan grass, Johnson grass, Velvet grass
Alkaloids	Reed canarygrass, Bindweed, Lupin, Larkspur, Jimsonweed
Fungal endophytes	Tall fescue, Perennial ryegrass
Nitrate	Oats, Wheat, Cheeseweed, Pigweed, Sweet clover
Tannins	Birdsfoot trefoil, Lespedeza, Sainfoin, Crown vetch, Oak, Bitterbrush, Blackbrush,Mountain mahogany
Terpenes	Sagebrush, Juniper, Pine trees, Bitterweed, Rubberweed

Regulating Intake of Toxins

Many people assume all plants that contain toxins cause death or decrease production. In reality, few plants that contain toxins that are eaten by livestock cause overt signs of poisoning. At high concentrations, most toxins cause plants to be unpalatable. In most cases, toxins cause livestock to limit their intake of plants. Livestock limit their intake of plants high in toxins through feedback mechanisms that link the body with the palate. That feedback causes animals to stop eating a particular food and begin eating another one. The ability of livestock to pair a plant's flavor with negative feedback is why well-fed animals in familiar environments rarely over eat toxic plants and die (Provenza, 1996).

Whether livestock will eat a plant depends on several factors. Livestock are least likely to eat a plant if it is low in nutrients and/or contains high levels of acutely toxic compounds. They are more likely to eat plants high in nutrients and low toxins. For example, lambs offered unlimited access to alfalfa pellets eat limited amounts of grain laced with toxins, because the grain provides needed energy and variety in their diet. Well-fed lambs will only ingest a limited amount of toxins. On the other hand, when livestock have no other foods to eat, they may be forced to eat plants high in toxins. Hungry animals will often eat too much of a toxic plant and die rather than starve (Burritt and Provenza, 1989).

The rate at which toxins are eaten depends on how quickly they can be removed from the body. For toxic plants like larkspur that are high in nutrients, intake tends to be cyclical. Cattle gradually increase intake of a larkspur over several days. When they eat too much of the plant it causes a mild aversion, preference declines for a few days, then gradually increases because of the positive feedback livestock experience from nutrients in larkspur (Pfister et al., 1997). Likewise, sheep grazing a clover-grass pasture prefer to eat clover in the morning and grass in the afternoon, even though clover is higher in energy and protein than grass. Sheep may switch from clover to grass in part because white clover contains cyanide, and levels of cynanide in white clove peak around noon. Cyanide also causes food aversions in livestock.

Different species of animals vary in their susceptibility to different toxins, as do individual animals within a species. For example, sheep are more tolerant of larkspur alkaloids than cattle, but cattle are more tolerant of lupine alkaloids than sheep. The same is true within a species. Most goats prefer older to current-season's twigs of the shrub blackbrush, due to high tannin concentrations in current season's growth. However, about 10 to 20% of goats readily eat current-season's blackbrush, presumably because they can tolerate or detoxify tannins more effectively than other goats.

Toxin-toxin Interactions

Different kinds and amounts of toxins in plants influence how much an animal can eat during a meal. Some toxins are complementary while others are antagonistic. Different toxins affect different metabolic pathways and are likely detoxified by different pathways (Provenza, 1996).

Livestock can eat more forage when the plants in their diet contain complementary toxins rather than when they are forced eat a single plant species with toxins. For example, lambs fed a single diet containing either oxalate, tannin or terpenes ate less than lambs fed a choice of all three diets. Mule deer also ate less when they were fed either sagebrush or juniper than when they were offered both sagebrush and juniper, plants that contain different terpenes. In Australia, brushtail possums ate more food when fed two diets, one with phenolics and the other with terpenes, than possums that ate a diet with only one of these toxins. Finally, in Texas sheep ate more when they were able to mix oak brush (tannins) and four-wing saltbush (saponins) rather than either plant alone.

Conversely, livestock cannot increase their intake of toxic foods when toxins are antagonistic. For example, lambs offered two foods, one containing the alkaloid sparteine and the other containing saponins, did not eat more total food when compared with lambs offered one food containing either saponin or sparteine (Burritt and Provenza, 2000).

Eating Toxins Is Expensive

Toxins affect the nutrient status of the body in several ways: 1) They limit intake of a particular forage; 2) some reduce the digestibility of nutrients; and 3) additional nutrients are required to get rid of toxins in the body.

It is difficult to determine the cost of excreting toxins because most detoxification pathways are unknown. Where these pathways are known, the costs of detoxification are substantial. Most toxins are lipophilic compounds (fat loving) that must be changed into hydrophilic substances (water loving) before they can be eliminated from the body. This conversion requires additional energy and protein. Furthermore, toxins may also disrupt the body's acid/base balance forcing the body to use more protein and energy (Provenza et al., 1992).

Implications

Range sites in good condition provide livestock with a variety of species with varying levels of nutrients and toxins. These sites supply livestock with the nutrients they need to eat and detoxify plant toxins and provide more even grazing of all plant species. On the other hand, range sites in poor condition often offer livestock limited numbers of plant species many of which contain high levels of toxins. Livestock on these sites will likely overuse palatable plants and avoid toxic plants because they do not have adequate nutrients to detoxify toxic compounds. Over time these sites become dominated by a few species high in toxins and unpalatable to livestock.

Livestock also benefit from grazing pastures that contain mixtures of plants, which enable them to eat a variety of foods that contain different kinds and amounts of toxins. People assume incorrectly that most grasses and many forbs do not contain toxic compounds. Since we don't know how most toxins in plants will interact with each other, any mixture of plants increases the odds livestock can avoid over-ingesting any one toxin and still meet their nutritional needs.

Researchers often try to predict the intake of plants based on their nutritional composition using mathematical equations. However, equations based merely on nutrient concentrations do not accurately predict preference or intake of most plants or mixtures of plants. We fail to appreciate the influence of toxins on intake because most toxins are not acutely lethal nor do they cause birth defects or other health problems in animals. Toxins undoubtedly play a role in regulating the intake of many plants that are not considered toxic because they are not acutely poisonous.

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