USDA-ARS Poisonous Plant Research Laboratory: History and Current Research on Western North American Rangelands

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On the Ground

- Poisonous plants on western North American rangelands have historically been troublesome to livestock producers.
- Research on toxic plants was initiated by the United States Department of Agriculture in the late 1890s to solve problems for the livestock industry.
- The United States Department of Agriculture Agricultural Resource Service Poisonous Plant Research Laboratory in Logan, Utah continues to provide research-based solutions to poisonous plant problems besetting livestock producers, hobby farmers and small holders, veterinarians, and extension personnel.
- Principal plants of current research interest include larkspur, lupine, locoweed, selenium accumulating plants, pyrrolizidine alkaloid-containing plants, and ponderosa pine.

Keywords: poisonous plants, cattle, sheep, livestock, toxic, plant secondary compounds.

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The colonization of western North America brought domestic livestock to this continent in the early 1500s, when cattle were introduced into Mexico by Gregorio Villalobos in 1521. Cattle, sheep, and horses were introduced into the western United States by Coronado in 1540. However, the real beginning of the range livestock industry in the western United States is attributed to the movement of settlers and livestock into the Mississippi Valley, and these herds merged with livestock moving from Texas northward to other states. From about 1865 to 1895, 5 million head of cattle were moved north out of Texas. Forage on rangelands was considered to be limitless, and predators and thieves were the major worries for livestock producers. Poisonous plants were not a major concern given the extensive animal husbandry practices during that era.

Settlers in the Midwest had some experience with plant toxicity in humans and livestock from milk cows eating white snakeroot (*Ageratina altissima*), but large-scale losses of livestock to poisonous plants were rare on eastern rangelands. The range livestock industry in the United States boomed after the Civil War as large numbers of cattle and sheep were trailed onto expansive western rangelands. Soon thereafter, large losses of livestock from poisonous plants were reported as ranchers encountered unknown plants such as locoweeds (*Astragalus* and *Oxytropis* spp.) and larkspurs (*Delphinium* spp.), among others (Fig. 1.).

History of the Poisonous Plant Research Laboratory, Logan, Utah[i]

Spurred on by numerous accounts of field losses, United States Department of Agriculture (USDA) officials decided to act. V. K. Chesnut, assistant botanist for the USDA, was assigned to begin field investigations in 1895 in the western US, including Utah. Chesnut and his associate, E.O. Wilcox, made field investigations in Utah and other states focusing on locoweeds and larkspurs (Figs. 2 and 3). In 1901, six different divisions (Botany,

[i] The 70th Annual Society of Range Management Annual Meeting will be held in St. George, Utah 29 January–2 February 2017. This article highlights Utah range science and management. For more information on SRM Red Rock & Rangelands 2017 see http://rangelands.org/srm17/.

Figure 1. A, *Astragalus mollissimus*. **B,** *Delphinium barbeyi*. Photos courtesy of Al Schneider©, www.swcoloradowildflowers.com.

Pomology, Vegetable Physiology and Pathology, Agrostology, Gardens and Grounds, and Seeds) within the USDA were consolidated into the Bureau of Plant Industry (BPI). One initial emphasis of the BPI was investigations in systematic botany, including the development of a herbarium for reference and research. An outgrowth of the herbarium effort was the collection of information by BPI botanists on the distribution of poisonous plants, including "their identity and harmful characteristics." The renowned animal physiologist Dr C. D. Marsh was hired in 1905 as 'Animal Physiologist in Charge' of Poisonous Plant research, where Marsh and coworkers initially worked at field stations in Hugo, Colorado and Imperial, Nebraska. In 1908 these temporary stations were closed and moved to Gunnison, Colorado, and then again to Greycliff, Montana until 1914. These early research stations were temporary locations tasked with the study of site-specific toxic plant problems, such as locoweed and larkspur.

In 1915 the investigation of poisonous plants was transferred from the BPI to the Division of Pathology in the Bureau of Animal Industry, and also moved to a more permanent research facility, the Salina Experiment Station, in Fish Lake National Forest near Salina, Utah (Fig. 4). At the Salina Experiment Station research continued on locoweed, larkspur, lupine, and other toxic plants under the direction of Dr Marsh. Additional studies were conducted on big head poisoning in sheep, oak brush poisoning in cattle, and sneezeweed and milkweed poisoning in sheep (Fig. 5). The harsh winters precluded winter occupancy of the Salina Experiment Station, and the researchers decamped to Washington, DC during each winter. Dr C. D. Marsh was head of the poisonous plant investigations in the western United States (including Salina, Utah) from 1905 to 1930, and was eventually replaced as director at Salina by Mr A. B. Clawson (animal physiologist).

The pioneering efforts of C. D. Marsh and his coworkers over the years led directly to the formal creation in 1955 of the Poisonous Plant Research Laboratory (PPRL[ii]) within the Agricultural Research Service (ARS). The Salina Experiment Station was closed in 1955. Its permanent replacement was established in Logan, Utah on the campus of Utah State University (USU) with Dr Wayne Binns, DVM as the first research leader. Dr Binns, then head of the Department of Veterinary Science at USU, was hired as the first Director of the USDA-ARS Poisonous Plant Research Laboratory and was provided office space at USU. Dr Binns initiated research on halogeton, larkspur, and field studies of ewes giving birth to cyclopic or "monkey-face" lambs. He further initiated studies into "crooked calf syndrome." In 1957 Mr Lynn F. James (Animal Scientist) was hired to assist Dr Binns' research efforts. L. F. James completed his PhD degree in 1966 on halogeton poisoning in sheep, and was appointed research leader in 1972 after Binns stepped down due to health problems. PPRL buildings adjacent to the main USU campus were constructed in the late 1950s, and were intended to be temporary research facilities. These "temporary" facilities were finally replaced in 2004 by a new, state-of-the-art facility, under the direction of Dr James. Dr Kip Panter (Reproductive Toxicologist) replaced Dr James as research leader in 2007.

Economic Impact of Poisonous Plants

Losses to the livestock industry from poisonous plants in western North America and across the world come in many forms. These include death losses from acute and chronic intoxication, reduced weight gains, reduced reproductive efficiency (lack of conception, embryo loss, abortion, male infertility, lack of mother-infant bonding and suckling, uterine infections), and animals which fail to thrive. Exposure to some toxic plants such as locoweeds, may predispose animals to other health problems, such as right heart failure in brisket disease. Further, exposure to poisonous plants may reduce the effectiveness of vaccines and other routine veterinary management practices, leading to subtle losses later in the production cycle. Other insidious costs include increased costs for fencing and for range riders, veterinary fees, loss of forage on pastures and rangelands due to changes in management, forced changes in grazing and livestock management, and reductions in land values. In expansive

[ii] Visit the PPRL website at http://www.ars.usda.gov/pacific-west-area/logan-ut/poisonous-plant-research/.

Figure 2. Field work showing the primary mode of transportation used for investigating poisonous plant cases throughout the West, for example in locoweed poisoning (1905).

mountainous areas, dead or debilitated livestock attract and retain predators such as bears, complicating herd management and potentially increasing death losses. Holechek[1] estimated that livestock poisoning by plants results in over $500 million in losses to the livestock industry annually in the 17 western US states. Research advances have tempered livestock losses to a number of poisonous plants, but depending on the individual ranch situation, and yearly variation in the populations and/or toxicity of plants in specific areas, the total financial loss attributable to poisonous plants is still a substantial financial burden on the livestock industry.

Historical and Current Research at the PPRL

Research at the PPRL has provided some notable success stories for the livestock industry in western North America, including Utah. To illustrate a few of these successes, below we share vignettes of toxic plant research that have provided scientific information and technology to solve various problems on rangelands. These examples also serve to illustrate the mission of the PPRL—to identify toxic plants and their toxins, determine how the plants poison animals, and develop diagnostic and prognostic procedures for poisoned animals. Furthermore, the PPRL mission is to identify the conditions under which poisoning occurs, and develop management strategies and treatments to reduce losses. Numerous publications have resulted from this work, many of which are included in the online supplemental references at http://dx.doi.org/10.1016/j.rala.2016.08.008.

Veratrum (Fig. 6). Research during the late 1950s and early 1960s on the cause of the cyclops lamb syndrome in Idaho was crucial and groundbreaking. Roughly 25% of pregnant ewes were giving birth to “monkey-faced” lambs. At times ewes carried the deformed lambs for extended periods past their expected parturition dates, killing the ewe. Field studies were conducted to screen potentially toxic plants, but the breakthrough came when a Basque sheepherder mentioned to a graduate student (D. Jesse Wagstaff) assisting with the project that a specific plant (*Veratrum californicum*) made the pregnant ewes ill. Subsequent feeding trials confirmed that Veratrum was indeed the cause of the deformed lambs when ingested by pregnant ewes on gestation days 13 to 15. In 1962 Dr Richard Keeler (Chemist) initiated research that eventually resulted in the identification and naming of the steroidal alkaloid cyclopamine as the toxin. Cyclopamine was found to inhibit the hedgehog (Hh) signaling pathway, which plays a critical role in embryonic development and cell division. More recently, aberrant Hh signaling has been implicated in several types of cancer. Inhibitors of the Hh signaling pathway, including cyclopamine derivatives, have been targeted by pharmaceutical companies as potential treatments for certain cancers (e.g., basal cell carcinoma, medulloblastoma, and small cell lung cancer) and other diseases associated with the Hh signaling pathway.

Halogeton (Fig. 6). *Halogeton glomeratus* is an invasive plant that has historically caused serious death losses in sheep herds grazing desert rangelands in Utah and elsewhere in the Great Basin. Halogeton is grazed readily by sheep and cattle. Halogeton contains oxalates, and typically poisons animals during late fall, winter, and early spring. Studies by Dr James and coworkers in the 1960s and 1970s unraveled many aspects of this complicated poisonous plant problem. They determined the metabolic fate of ingested oxalates in ruminant livestock, and developed management recommendations that greatly reduced the risk of losing grazing animals. For example, they recommended that hungry or thirsty animals not be trailed or released into halogeton-infested areas. Further, they showed that sheep could slowly adapt over several days to increasing amounts of oxalate in their diet, such that fatalities can largely be avoided by allowing

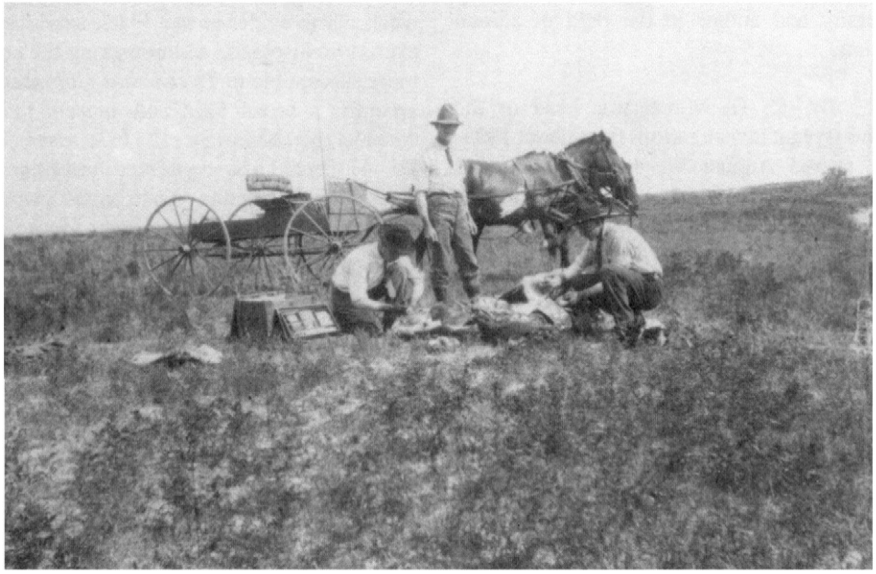

Figure 3. Post mortem examination of a suspected field case of a plant poisoning in 1906.

grazing animals to consume small amounts of the plant for several days. These and other recommendations, if followed, have largely eliminated halogeton as a serious threat to grazing livestock.

Lupine (Fig. 6). Cattle producers with pregnant cattle grazing on rangelands with various *Lupinus* spp. began reporting incidences of deformed calves in the 1950s and 1960s, a syndrome known as crooked calf syndrome. The term "crooked calf syndrome" is used to describe a syndrome of skeletal malformations in newborn calves that typically includes a twisted spine, neck, and one or both forelimbs. An associated deformity with the more obvious skeletal deformities is a cleft palate. At times, these deformities may not allow the calf to walk or nurse, and most die or are destroyed. In the 1960s veterinarian J. LeGrand Shupe at the PPRL experimentally confirmed that ingestion of lupine was the cause of the syndrome. Dr Keeler determined in 1976 that the alkaloid anagyrine was the teratogenic compound in lupine responsible for the deformed calves. Further work by Drs Keeler and Panter in 1989 showed that another class of alkaloids (piperidine, including ammodendrine, and N-methyl ammodendrine), found in some lupine species, were also teratogenic and caused the same defects as anagyrine. Dr Stephen Lee (Chemist) has continued research studies on the identification and isolation of lupine alkaloids. Interestingly, Dr Panter also found that these alkaloids reduced fetal movement during the critical stage of pregnancy (days 40-100) when the rapidly growing fetus is essentially

Figure 4. The Salina Experiment Station (1916).

Figure 5. Camp Macrocephala in the Wah Wah Valley in west central Utah pursuing research on big head in sheep (2 April 1936).

frozen into the deformed state because the alkaloids inhibit fetal movement without injuring the mother. Cleft palates result from the physical impedance of the tongue as it prevents normal closure of the developing palate. Recent research has shown that *Conium* and *Nicotiana* spp. also contain teratogenic alkaloids, with a similar effect in livestock when eaten during gestation. Dr Panter's work using a goat model of teratogenicity has become an important tool in understanding the mechanism of cleft palate induction, and has spurred biomedical research to repair cleft palates in utero as a potential fetal intervention for cleft palate repair in the human fetus.

Locoweeds (Fig. 1). Much of the work done by USDA scientists in the late 1800s and early 1900s was conducted in response to pleas for help from livestock producers dealing with locoweed (i.e., *Oxytropis* and *Astragalus* spp.) poisoning in their herds. When locoweeds are consumed by livestock for greater than 5 to 7 days, a plethora of negative effects are seen, including neurological dysfunction, depression, loss of appetite, emaciation, reproductive disturbances, birth defects, abortions, and lack of maternal–offspring bonding and nursing at birth. The toxin in locoweeds, the indolizidine alkaloid swainsonine, was first reported in a related plant species in Australia by Dr Steven Colegate, and subsequent work by now-retired USDA chemist Dr Russell Molyneux and Dr James found that swainsonine was also the toxin in US locoweeds. Dr Dale Gardner (Chemist) has continued research studies on chemical identification and isolation of swainsonine and related polyhydroxy alkaloids. Dr James worked for more than 40 years on the effects of locoweed on animal health; Dr Panter has more recently demonstrated the disastrous effects of locoweed on female and male reproduction. Dr Bryan Stegelmeier (Veterinary Pathologist) has conducted numerous animal studies to provide diagnostic guidelines, and has also elucidated the effects of locoweed on animal health and physiology. Recent work in New Mexico by Dr Rebecca Creamer and colleagues, and by Dr Daniel Cook (Plant Biologist) at the PPRL, has shown that swainsonine is produced, not by the locoweed plant itself, but rather by fungal endophytes growing within locoweed plants. Dr Cook has developed a quantitative assay to determine concentrations of endophyte within plants, and further determined that the locoweed populations can be classified as either one of two chemotypes, with one chemotype containing sufficient swainsonine to poison livestock, and a second chemotype with very low or nil amounts of swainsonine. Dr Cook's work has shown that the chemotype of the plant is directly related to the amount of fungal endophyte producing swainsonine, providing other avenues for research and control. Finally, one means by which swainsonine in locoweeds poisons livestock is through inhibition of glycoprotein processing in mammalian cells. The capability of swainsonine and related compounds to disrupt cell functioning has lead biomedical researchers to investigate swainsonine and related toxins for their potential as therapeutic agents for various diseases, including cancer, diabetic treatments, and as antiviral and antiparasitic drugs.

Larkspur (Fig. 1). *Delphinium* spp. is commonly known to poison cattle on the foothill and mountain rangelands of North America. As larkspurs are generally palatable to cattle, but may contain high concentrations of acutely toxic alkaloids, death losses on larkspur-infested rangelands may exceed 10% per year. The primary toxic species in the Intermountain West are *D. barbeyi* and *D. occidentale* (tall larkspurs), and *D. nuttallianum* and *D. andersonii* (low larkspurs). Dr Gardner has conducted chemistry studies to identify and isolate the various larkspur alkaloids, and to provide purified compounds for toxicity testing; Dr Kevin Welch (Toxicologist) and Dr Panter have determined the relationship between the type of alkaloid and level of toxicity to animals. For the past 3 decades, research by Dr Michael Ralphs (Range Science,

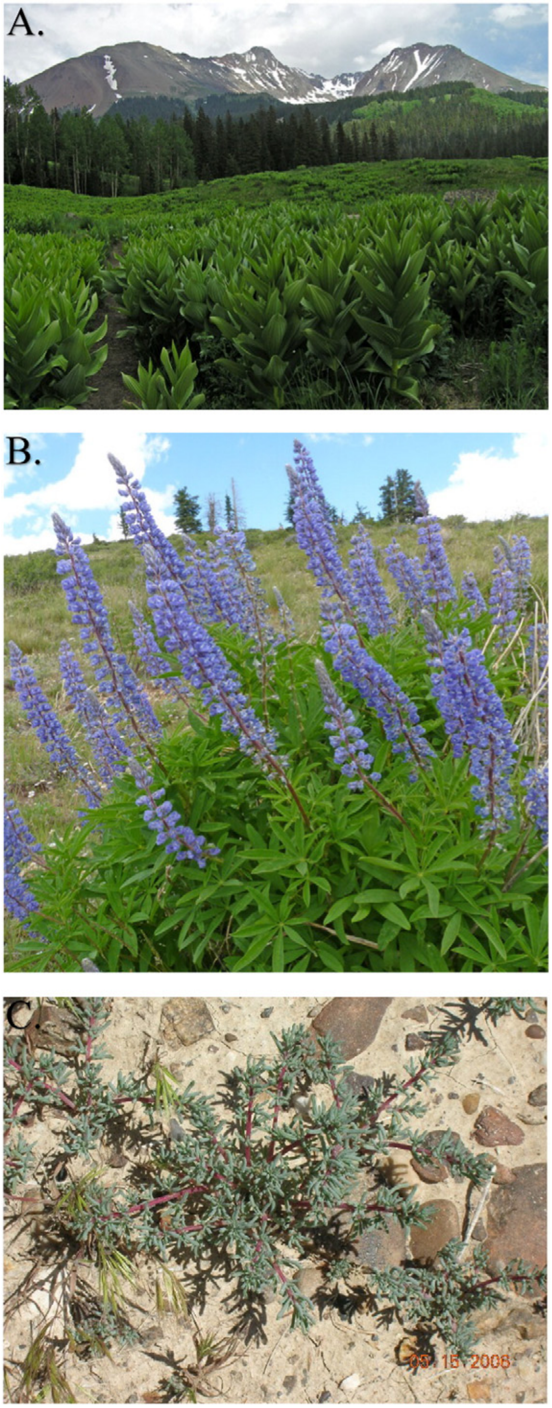

Figure 6. A, *Veratrum californicum*. **B,** *Lupinus argenteus*. **C,** *Halogeton glomeratus*. Photos **A** and **B** courtesy of Al Schneider©, www.swcoloradowildflowers.com. Photo **C** courtesy of Sheri Hagwood, hosted by the USDA-NRCS PLANTS Database.

retired) and Dr Jim Pfister (Range Science) has focused on understanding when cattle consume larkspurs in relation to plant toxicity and other environmental and management factors. Dr Ralphs also produced comprehensive recommendations for herbicidal application to economically reduce tall larkspur populations; if followed, these recommendations have resulted in >80% mortality of tall larkspurs with an expected duration of 10 to15 years. Dr Pfister determined that cattle consume the majority of tall larkspur (*D. barbeyi* and *D. occidentale*) after elongation of flowering stalks and subsequent flowering. These studies resulted in the "toxic window" management recommendation, whereby cattle can be grazed on tall larkspur-infested rangelands for 4 to 6 weeks early in the grazing season, removed during the time of greatest danger (i.e., the toxic window), then grazed again with little risk later in the season.

Tall larkspurs may appear to be similar to the untrained eye, but even so different larkspur species and populations often have unique alkaloid profiles. For example, two tall larkspurs (*D. barbeyi* and *D. occidentale*) have similar leaf structure and growth form but have been distinguished by pubescence and flower morphology. However, they have different and often unique alkaloid profiles, allowing their classification using chemotaxonomy and genetic markers. Dr Cook has determined that potentially toxic larkspur populations appear to be limited to specific geographical distributions; the spatial distribution of various larkspur species and even different populations with different potential to poison grazing cattle is emerging as an important management tool to reduce the risk of losses[iii].

Looking Ahead: Current and Future Research

The PPRL currently has 10 scientists and 17 support staff, representing various disciplines (Table 1). An interdisciplinary team of scientists provides an interdisciplinary approach of applied and basic research to develop solutions to intoxication. The integration of scientific disciplines is a major strength of the PPRL, and is the only such interdisciplinary laboratory studying toxic plants in the world. Toxic plant research problems examined with a multi-disciplinary effort have a greatly increased probability of success.

The PPRL scientists are currently pursuing five interrelated areas of investigation. These include: 1) developing science-based guidelines for grazing livestock on rangelands infested with toxic plants; 2) reducing the risks of livestock losses due to variations in toxin concentrations in plants over time by determining environmental and genetic influences on toxin accumulation; 3) enhancing feed and food safety by improving analytical methods for analyzing plant and animal tissues, and determining clearance times of toxins from animal tissues (i.e., toxicokinetics); 4) developing guidelines for diagnostic and prognostic evaluation to reduce negative impacts of poisonous plants on livestock reproduction and embryo/fetal growth; and 5) developing guidelines to aid producers and land managers in making genetic-based herd management decisions to improve livestock performance and animal safety on rangelands infested with poisonous plants.

[iii] For more information regarding larkspur, see "Grazing Tall Larkspur Ranges: A Livestock Producer's Decision-making Handbook (http://extension.usu.edu/behave/files/uploads/Fact_Sheets_App/Larkspur-Handbook-FINAL.pdf).

Table 1. Interdisciplinary scientific positions at the PPRL, Logan, Utah

Discipline	Primary research emphasis
Reproductive toxicology	Effects of toxic plants on reproduction; teratology
Animal/range science	Effects of toxic plants on animal nutrition and behavior; grazing management; restoration of degraded rangelands
Natural products chemistry	Chemistry of toxic plants
Veterinary pathology	Diagnosis and prognosis of plant poisoning
Toxicology	Toxicology aspects of poisonous plant ingestion
Pharmacology/physiology	Pharmacological and physiological effects of plant toxins on animals
Plant biology	Factors influencing toxin concentrations in plants
Biochemistry/physiology	Mechanisms of intoxication

Climate Change and Poisonous Plants

Conditions on the range and pasture lands in the western United States are influenced greatly by environmental conditions. The severity of problems from poisonous plants on rangelands is very sensitive to changes in climatic conditions (i.e., precipitation and temperature); global climate change will likely influence the interaction of poisonous plants and grazing livestock. Climate change is expected to result in changes in weather patterns, as well as elevated atmospheric CO_2. These changes may influence the size and density of plants, both of which may influence toxicity and the diet selection of grazing livestock. Recent studies at the PPRL have shown that populations of low larkspurs (*Delphinium nuttallianum* and *D. andersonii*) are sensitive to winter and spring climatic conditions. Other studies have shown that elevated atmospheric CO_2 increases the biomass of *Lolium perenne* (perennial ryegrass) and *Datura stramonium* (jimsonweed) and may influence the concentrations of toxins in some plants. Lastly, a complicating factor is that climate change may influence the palatability and nutritional content (e.g., crude protein) of range plants, including poisonous plants. Ultimately, it is difficult to predict how changes in weather patterns and atmospheric carbon dioxide will affect individual plant species or populations. Future research will continue to examine the population response of selected toxic plants such as larkspurs, and also examine the influence of environment on concentrations of plant toxins.

Improving the Genetic "Fit" of Grazing Animals to Cope with Poisonous Plants

In our increasingly sophisticated world, the identification and measurement of genomic features (e.g., DNA sequence and gene expression) is becoming less expensive and increasingly routine. One solution to losses of grazing livestock from toxic plants involves the compatibility of animals to their grazing environment. Ranchers have selected and culled animals within herds for generations seeking to emphasize specific traits or advantages to increase animal well-being and ranch profits. Genetic selection of livestock has the potential to further enhance production efficiency and animal welfare. Selection of livestock that are better adapted to pastures and rangelands is a real possibility. In addition, it seems increasingly likely that livestock producers will select grazing livestock that are better adapted to future climate change and to resist poisoning by plants. Matching animal species, breeds, or genotypes to the proper environment may provide one avenue to reduce the negative effects of toxic plants on animal welfare. Researchers in Texas[2] selected lines of goats based on their consumption of juniper; goats that consumed large amounts of juniper possessed the ability to excrete monoterpenes more quickly. Researchers in Idaho have shown that there is a genetic basis for sheep selection of sagebrush, providing an avenue to improve sheep production on sagebrush ranges, and provide rangeland management options through selection for dietary preferences.[3] Other researchers have identified a single nucleotide polymorphism in the dopamine receptor D2 gene that is associated with resistance to fescue toxicosis.[4] Using this research approach, studies by Dr Ben Green (Pharmacologist) on larkspur (*Delphinium* spp.) poisoning identified substantial animal-to-animal variation in five breeds of cattle for resistance and susceptibility to larkspur.[5] Preliminary work suggests that each individual animal's genetic predisposition for larkspur poisoning can be predicted from its DNA sequence. The ultimate goal of Dr Green's research is to identify a gene marker that will allow producers to identify susceptible and resistant animals by submitting a saliva, blood, or hair sample to a genetic testing laboratory. Beef producers could then use that information for marker-assisted selection to improve the genetics of their herds for their specific rangeland conditions. There are currently commercially available genetic tests for coat color, production traits and meat. This same approach may also prove valuable for other toxic plants such as lupine (*Lupinus* spp.). In the future, continued advances in genetic tools and reductions in cost will allow producers to select for locally adapted animals best suited to graze on their specific rangelands.

Fingerprints of Plant Toxins in Livestock Stomach Contents

Finding dead animals in pastures or rangelands can be a traumatic and costly experience for livestock producers. To minimize or prevent future losses, it is often imperative to quickly determine the cause of the death of an animal, whether the cause is disease, poisonous plant, or other means. While evaluation of stomach contents is a valuable tool, plant material in the rumen or stomach is macerated and difficult to visually identify. Dr Cook recently developed an alternative diagnostic tool to determine whether a specific poisonous plant was ingested, using a genetic tool called polymerase chain reaction (PCR). PCR is a tool that may allow detection of the genetic material from a specific plant within a complex matrix such as rumen or stomach contents. In this research, Dr Cook developed genetic material (i.e., oligonucleotide primers) specific to larkspur (*Delphinium occidentale*). Using these primers, the DNA fingerprint of larkspur was detected in cattle rumen samples under controlled circumstances. In addition, larkspur was detected in a matrix of ruminal material where the amount of larkspur was far less than what one would expect to find in the rumen contents of a poisoned animal. The PCR-based technique holds promise to diagnose larkspur poisoning, and will likely be useful for other poisonous plants growing on rangelands in western North America.

Food Safety and Toxin Contamination of Food Products

A number of invasive weeds (e.g., *Cynoglossum officinale*, houndstongue; *Senecio* spp.) across the Intermountain West contain toxic pyrrolizidine alkaloids (PAs). Most are not palatable to livestock but are only eaten when other forage is scarce. However, if accidently harvested from hay meadows or grain fields, they contaminate prepared feeds, grains, and food, which can then be eaten by animals or humans. These alkaloids can also contaminate milk, honey, and pollen products. Human poisonings may occur as a result of food contamination or when PA-containing plants are used for medicinal purposes (e.g., *Symphytum officinale*, comfrey tea). Poisoning by PAs in livestock is often slow and progressive, as affected animals develop disease months after exposure because PA metabolites (i.e., PA adducts) may persist for months or years in the body. Dr Stegelmeier has developed a successful small animal bioassay using chickens. Chicks are highly sensitive to PA poisoning and they are small enough to test minute amounts of highly purified PA material provided by Dr Colegate and Dr Gardner. This approach provides an avenue to conduct in-depth food safety research that would not be possible otherwise.

Livestock that graze poisonous plants but are not fatally affected are a source of concern if humans subsequently consume contaminated meat or milk products. For example, poisoning in humans from white snakeroot-contaminated milk may have been the leading cause of death and disability in the Midwest and Upper South regions of the United States during the late 18th century. Those deaths probably included Nancy Hanks Lincoln, mother of nine-year-old Abraham Lincoln. The potential for transfer of plant-associated toxins to the meat or milk of affected animals has been studied by Dr James, Dr Panter, Dr Stegelmeier, Dr Welch, Dr Zane Davis (Biochemist), Dr Green, and Dr Lee. Past and current studies have focused on the possibility of contamination of food products from PA-containing range plants, locoweeds, larkspurs, and rayless goldenrod (*Isocoma* spp.). Research related to food safety and possible contamination of food products or forages will continue as new methods and technology are developed that will improve the ability to measure toxins and residues in animals.

Alter Cattle Diet Selection Through Rangeland Restoration

Cattle grazing on degraded rangelands in the Channel Scablands of eastern Washington often have poor choices for forage, including lupine (*Lupinus leucophyllus*), which may cause large numbers of calf losses from crooked calf syndrome. In addition to lupine, other forage choices are weedy forbs such as fiddleneck (*Amsinckia* spp.), rush skeletonweed (*Chondrilla juncea*), and annual grasses such as medusahead (*Taeniatherum caput-medusae*). Under these conditions, pregnant cattle often consume large quantities of lupine after the annual grasses and other weedy forage desiccate and mature in mid-to-late summer. Improved grass and forb species that will establish and persist in harsh environments of the Channel Scablands are lacking. Dr Panter and Dr Clint Stonecipher (Range Science), in cooperation with scientists from the USDA-ARS Forage and Range Research Laboratory (Logan, Utah) are conducting studies to determine if forage kochia (*Bassia prostrata*) seeded in mixtures with improved grass species will provide reliable alternative forages for cattle late in the grazing season. Furthermore, they are determining if these seeded species will suppress existing cheatgrass and medusahead populations, and improve range conditions and dietary choices for grazing cattle, with the end result of reducing the incidence of crooked calf syndrome.

Conclusions

Livestock poisoning by plants results in substantial monetary losses to the livestock industry throughout western North America. On rangelands with serious toxic plant problems, the economic burden on livestock producers and other users is intensified because significant amounts of nutritious forage are wasted, and management costs are increased due to the threat of plant-related livestock losses. The PPRL has provided leadership across western North America and in other countries worldwide in conducting research relevant to the livestock industry and other customers using an integrated, interdisciplinary approach. The ultimate goal of PPRL research is to develop research-based solutions to reduce livestock losses from toxic plants. PPRL research has resulted in a number of noteworthy successes that have benefited customers across the region and the globe[iv].

[iv] For more information concerning specific poisonous plants see Agriculture Information Bulletin 415 "Plants Poisonous to Livestock in the Western States" (http://www.ars.usda.gov/is/np/PoisonousPlants/PoisonousPlants.pdf).

Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.rala.2016.08.008.

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