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Grazing of spotted locoweed (Astragalus lentiginosus) by cattle and horses in Arizona

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ABSTRACT: Spotted locoweed (Astragalus lentiginosus var. diphysus) is a toxic, perennial plant that may, if sufficient precipitation occurs, dominate the herbaceous vegetation of pinyon-juniper woodlands on the Colorado Plateau. Six cow/calf pairs and four horses grazed a 20-ha pasture with dense patches of locoweed in eastern Arizona during spring 1998. Locoweed density was 0.7 plants/m² in the pasture. Locoweed averaged 30.4% NDF and 18.4% CP. Concentrations of the locoweed toxin, swainsonine, fluctuated from 1.25 to 2 mg/g in locoweed. Horses ate more (P < 0.01) bites of locoweed than did cows (15.4 and 5.1% of bites, respectively). Horses generally increased locoweed consumption over time since they ate approximately 5% of bites in the preflower stage compared with 25% of bites in the pod stage. Cattle consumed almost no locoweed (<1% of bites) until the pod stage, when they increased consumption to 15% of bites. Horses were very avid (approximately 65 to 95% of bites) in selecting the small quantities (approximately 40 to 150 kg/ha) of available green grass, and it appeared that their propensity to eat scarce green forage influenced their locoweed consumption as well. Horses ate relatively little dry grass, even when it was abundant, whereas cattle ate large amounts of dry grass until green grasses became more abundant. Calves began eating locoweed on the same day as their dams and ate approximately 20% of their bites as locoweed. Serum concentrations of swainsonine were higher (P < 0.05) in horses than in cattle (433 vs. 170 ng/mL, respectively). Baseline swainsonine was zero in all animals, but swainsonine was rapidly increased to above 800 ng/mL in serum of horses as they ate locoweed. Horses exhibited depression after eating locoweed for about 2 wk; after 5 wk of exposure, horses became anorectic and behaviorally unstable. Although limited in scope, this study indicates that horses should not be exposed to spotted locoweed.

Key Words: Astragalus lentiginosus, Food Preferences, Grazing Behavior, Poisonous Plants

Introduction

Locoweeds are toxic plants of the genera Astragalus and Oxytropis that contain the indolizidine alkaloid, swainsonine. Collectively, locoweeds may be the most serious poisonous plant problem on the western U.S. rangelands (James and Nielson, 1988). Swainsonine inhibits the lysosomal enzyme α-mannosidase resulting in accumulation of incompletely processed oligosaccharides, loss of cellular function, and cell death (Dorling et al., 1980). Further, swainsonine’s inhibition of Golgi mannosidase II alters glycoprotein synthesis, processing, and transport. This results in dysfunctional cellular adhesion molecules, circulating hormones (e.g., insulin), and various membrane receptors. Clinically, symptoms of intoxication include depression, proprioceptive deficits, intention tremors, nervousness when stressed, emaciation, impaired reproduction, and occasionally, death. Many of the clinical signs and lesions are reversible; however, with chronic poisoning, irreversible neurological lesions occur and the damage is permanent (Marsh, 1909; James and Van Kampen, 1971).

Spotted locoweed (Astragalus lentiginosus) is a perennial plant complex with 36 varieties that grows throughout portions of the western U.S. from Arizona to Montana (Barnaby, 1964). Spotted locoweed (Astragalus lentiginosus var. diphysus) occurs in elevations ranging 1,440 to 2,250 m across northern and west central Arizona, southeastern Utah, southwestern Colorado, and eastern New Mexico, and can become dominant on sandy soils in yucca-grassland and pinyon juniper woodlands (Barnaby, 1964). Aside from the winter-grazing study in southern Utah on var. wahweapensis...
by Ralphs et al. (1988), there is no information available pertaining to livestock consumption of A. lentinginosus. Thus, the objective of this study was to investigate locoweed consumption patterns in cattle and horses in relation to locoweed phenology and toxicity.

Methods

Six beef Shorthorn cow–calf pairs (cow weight = 554 ± 21 kg) and four 2-yr old horses (two mares; two geldings; 375 ± 10 kg) were used in the study. Horses were mixed breed (predominately Quarter Horse and Arabian cross). Calves were about 2 mo old. All animals were naive to spotted locoweed. The cattle had previously grazed a sagebrush range in southern Idaho, and the horses were purchased in southeastern Idaho. The livestock grazed a 20-ha pasture enclosed with electric fence approximately 17 km SE of St. Johns, Arizona (34°24′N 109°13′W; 2,040 m elevation). The dominant vegetation in the pasture was pinyon pine (Pinus edulis) and one-seed juniper (Juniperus monosperma), which formed a dense canopy in some areas, with some openings dominated by spotted locoweed. Open areas with few trees were dominated by needle-and-thread grass (Stipa comata), blue grama (Bouteloua gracilis), and globemallow (Sphaeralcea coccinea), with scattered big sagebrush (Artemisia tridentata) plants. Soils on the study site were xeric and sandy (order aridisols and suborder orthids; USDA, 1975).

Forage availability was determined weekly by clipping 30 0.5-m² plots placed along pace transects. Clipped samples were divided into dried and green grass, spotted locoweed, and other forbs, dried to a constant weight in a forced-air oven at 40°C, and then weighed. Spotted locoweed phenology was recorded weekly on 100 plants selected at random along three pace transects placed systematically on a grid pattern throughout the pasture. Locoweed density was determined in mid-May using 125 1-m² quadrats placed systematically throughout the pasture.

Clipped locoweed samples were used for nutrient analysis after being ground to pass a 1-mm screen in a Cyclone grinder. Spotted locoweed samples were composted for each week and then analyzed for NDF using Dacron bags in a modification of the Van Soest et al. (1991) method. Plant tissue was extracted with boiling neutral detergent using filter bags in a batch fiber analyzer (Ankom, Fairport, N.Y.). An elemental analyzer (NA 2100 protein nitrogen analyzer, ThermoQuest Italia S.p.A., Milan, Italy) was used to determine nitrogen content, and crude protein content was calculated (AOAC, 1990). Ten individual locoweed plants were selected at random each week, harvested, frozen, and then lyophilized and ground through a 1-mm screen. The plants were composited by week, and then the composite samples were analyzed for swainsonine (Gardner et al., 2008). Bite counts were used to determine animal diets (Pfister et al., 1988). Beginning at approximately 0630 each day, individual animals were focally sampled (Altmann, 1974) in a predetermined random order. Each animal was observed sequentially for 5 min. After all animals had been observed, the process was repeated during all active grazing periods until about 1900, when animals were placed in a corral for the night. Bites were categorized as green or dormant grass, shrubs, other forbs, and spotted locoweed leaf and stem or flower/pod. We defined an individual bite as a single cropping motion, always indicated by a head jerk, often accompanied by a visible sweep of the tongue in cattle, and independent of chewing motions. Based on spotted locoweed phenology, bite count data for comparing horses and cattle were divided into three periods corresponding to the vegetative, flower, and pod stages of growth; these periods were from April 17 to May 4 (18 d), May 5 to May 22 (19 d), and May 24 to June 2 (10 d). Two horses (A and B) were removed from the pasture on June 2 because they were noticeably intoxicated; the other two horses (C and D) were removed from pasture on June 4; cattle continued to graze until June 8.

Serum was collected weekly via jugular venipuncture and analyzed for swainsonine, a-mannosidase (Stegelmeier et al., 1995a), and serum biochemical variables, including aspartate amino transferase (AST). Previous studies have shown that AST is a good indicator of spotted locoweed poisoning in cattle (Buck et al., 1961). Serum AST activity has been associated with cellular damage including damage to the liver, skeletal muscle, heart, and other tissues (Aminlari et al., 1994). Of the many possible serum biochemical variables, cattle serum was examined only for AST, whereas horse serum was examined for numerous variables. Virtually all were within normal ranges even when horses were severely intoxicated; thus, only AST data will be presented here. This research was performed under veterinary supervision and with the approval of the Utah State University Animal Care and Use Committee.

Two horses (A and B) were removed from the locoweed pasture on d 47 and humanely euthanized and necropsied on d 50 of the study (June 5). The other two horses (C and D) were removed from the locoweed pasture on d 49, allowed to recover for 27 d, then humanely euthanized and necropsied. At necropsy, tissues were collected and prepared for histopathological examination using standard methods (Duncan and Prasse, 1986). Tissue from intoxicated horses was compared with normal horse tissue obtained in previous studies (Stegelmeier et al., 1996). Cattle were not necropsied because they showed no visible signs of intoxication.

Statistical Analysis

Horses and cattle diets were compared for each dietary component using the PROC MIXED procedure of SAS (SAS Inst., Inc., Cary, NC). The model included treatments (i.e., species) and animals nested within treatments, with repeated measures over time. Animals were a random factor in the model, and various options
Locoweed grazing by cattle and horses

Table 1. Standing crop (kg/ha ± SE, partial dry matter basis) on various dates in a locoweed-infested pasture comprising desert grassland and pinyon-juniper woodland in eastern Arizona, 1998

<table>
<thead>
<tr>
<th>Date</th>
<th>Dormant grass</th>
<th>Green grass</th>
<th>Forbs</th>
<th>Locoweed</th>
</tr>
</thead>
<tbody>
<tr>
<td>April 17</td>
<td>221 ± 38</td>
<td>43 ± 18</td>
<td>15 ± 6</td>
<td>907 ± 307</td>
</tr>
<tr>
<td>April 24</td>
<td>189 ± 27</td>
<td>61 ± 17</td>
<td>14 ± 7</td>
<td>796 ± 223</td>
</tr>
<tr>
<td>May 1</td>
<td>222 ± 38</td>
<td>139 ± 15</td>
<td>52 ± 21</td>
<td>895 ± 370</td>
</tr>
<tr>
<td>May 8</td>
<td>149 ± 331</td>
<td>108 ± 26</td>
<td>78 ± 31</td>
<td>768 ± 207</td>
</tr>
<tr>
<td>May 16</td>
<td>177 ± 35</td>
<td>154 ± 25</td>
<td>65 ± 21</td>
<td>585 ± 218</td>
</tr>
<tr>
<td>May 22</td>
<td>105 ± 16</td>
<td>101 ± 14</td>
<td>84 ± 19</td>
<td>683 ± 260</td>
</tr>
<tr>
<td>May 29</td>
<td>106 ± 20</td>
<td>122 ± 19</td>
<td>80 ± 24</td>
<td>866 ± 702</td>
</tr>
<tr>
<td>June 6</td>
<td>54 ± 23</td>
<td>224 ± 32</td>
<td>210 ± 65</td>
<td>929 ± 646</td>
</tr>
</tbody>
</table>

(e.g., compound symmetry and autoregressive) were examined to arrive at the best-fitting variance–covariance matrix. Serum swainsonine concentration was also examined using the PROC MIXED procedure. Statistical comparisons were not made on AST concentrations between horses and cattle because normal (i.e., baseline) values are not similar. Mannosidase results for cattle were eliminated because the assay used produced inconsistent results. The consumption of locoweed by horses and cattle was examined in relation to locoweed nutrient concentrations and the amount of dry and green standing crop on a weekly basis using the stepwise multiple regression procedure of SAS.

Results

Locoweed Availability, Nutrient Content, and Toxicity

Spotted locoweed density was 0.7 ± 0.2 plants/m² (range 0 to 6 plants/m²) over the entire pasture. Locoweed dominated the available forage (Table 1), far exceeding the amounts of other forage components that were available for grazing.

Spotted locoweed was a nutritious feed, averaging 30.4% NDF and 18.4% CP (Figure 1). Concentrations of the locoweed toxin, swainsonine, fluctuated from 1.25 to 2.0 mg; there was a tendency for swainsonine concentration to increase somewhat as locoweed plants matured (Figure 1).

Weather and Spotted Locoweed Phenology

The mean spring (98-yr average for March, April, and May) temperature and precipitation for St. Johns is 10.9°C and 4.4 cm, respectively (NOAA, 1998). About 42% of the annual total precipitation of 29.87 cm occurs during the summer months of June, July, and August from monsoon showers. The only measurable precipitation (0.6 cm) during the study occurred in late April, and the mean spring temperature in 1998 was 9.8°C (NOAA, 1998); thus, the weather during the study was cooler and drier than normal (Figure 2).

Most locoweed plants were a mix of vegetative and bud stages when the study began and quickly advanced to the bud and flower stages (Figure 3). By mid-May, most locoweed plants had a mixture of flowers and pods, and by early June, most were in the pod stage and at least partially desiccated.

Diet selection

Horses ate more (P < 0.01) locoweed than did cows (x̄ = 15.4 and 5.1%, respectively), and there was a period

![Figure 1](https://jas.fass.org/)

Figure 1. Nutrient content (percentage of NDF and CP on a DM basis) and swainsonine concentrations (mg/g, partial DM basis) in spotted locoweed plants during spring 1998 in Arizona.
× treatment interaction (Figure 4). Horses generally increased spotted locoweed consumption over time, whereas cattle ate little locoweed until later in the grazing season (Figure 4). Cows ate more dry grass (36.6 vs. 7.8%), other forbs (7.7 vs. 0.7%), and shrubs (1.9 vs. 0.1%) than did horses, whereas horses selected more green grass (75.9 vs. 48.6%) than did cows. There were period × treatment interactions for all diet variables except for shrubs.

Serum Chemistry and Pathology

There was a treatment × period interaction for serum swainsonine concentration ($P < 0.05$) since horses had higher swainsonine concentrations on three occasions during the study (Figure 5). When cattle began eating locoweed in late May, the swainsonine concentration in their serum was essentially the same as in horses. The AST concentration in horses was elevated during the entire study, whereas cattle AST concentrations rose gradually over a 6-wk period (Figure 5).

The first clinical signs of intoxication in horses were depression and lethargy (James et al., 1970). Horses exhibited depression after eating locoweed for approximately 2 wk. Depression was a subjective assessment since the horses stood with their heads down, were not attentive to their surroundings, and were reluctant to move. After eating locoweed for approximately 5 wk, their behavior became somewhat erratic, and they could change rapidly from being placid and docile to very nervous and excitable. Horses began to lose weight after eating substantial locoweed for several weeks.
Figure 4. Mean daily consumption (percentage of bites ± SE) by cattle and horses of locoweed, dry grass, green grass, and other forbs during spring 1998 in Arizona. Data are missing for May 18 and 19. Inserts A, B, C, and D show mean diet selection (percentage of bites ± SE) by cattle and horses for each experimental period corresponding to locoweed growth stages. Period 1 (preflower) was April 17 to May 4; Period 2 (flowering) was May 5 to 23; Period 3 (pod) was May 24 to June 1. An asterisk indicates a difference ($P < 0.05$) between cattle and horses for that period.
Figure 5. Blood serum concentration (ng/mL) of swainsonine and aspartate amino transferase (AST), and enzymatic activity ($\mu$mol/L) of $\alpha$-mannosidase in cattle and horses grazing a locoweed-infested pasture during spring 1998 in Arizona. Mannosidase activity is expressed as $\mu$mol/L produced in 45 min, and only horse data are given. An asterisk indicates a difference ($P < 0.05$) for swainsonine between cattle and horses for that date.

At the end of the study, all horses were severely poisoned, thin, and in poor condition. The two horses that were transported to Logan at the end of the study (C and D) had no further access to locoweed; nevertheless, they continued to lose weight over 27 d, even though their appetites appeared to be normal. They were reluctant to move, and when they did move, slight intention tremors were evident in all four legs. These tremors were symmetrical and the front and rear legs appeared to be equally affected. Neurological examinations found normal reflexes and no neurological deficits. Although their eyes were dull and appeared opaque, they were functional and no definite ocular or retinal lesions were grossly detected. These two horses began to move with less hesitation after locoweed was removed from their diet, but even so, intention tremors were noted in the rear legs when they were agitated.

At the postmortem examination, little subcutaneous or visceral adipose tissue was found in any of the horses. The two horses that were examined while poisoned (A and B) had 1.5 to 2 L of serous fluid in the peritoneal cavity. No other gross lesions were found in any of the four horses.

The animals that were euthanized while poisoned (A and B) had extensive vacuolation of most visceral and neurological tissue (James and Van Kampen, 1971). Nearly all neurons throughout the central and peripheral nervous system were vacuolated, but the most severe vacuolation was seen in large neurons of the basal ganglia, medulla, and the cerebellar Purkinje cells (Figure 6). The epithelium of the proximal convoluted renal tubules was severely vacuolated, as was the thyroid follicular epithelium (Figure 7) and exocrine pancreas. With the exception of neurological lesions, all the histological lesions had resolved at necropsy in the two animals that were removed from locoweed (C and D). In these animals, the cerebellar Purkinje cells were occasionally vacuolated. Additionally, there were increased numbers of pyknotic Purkinje cells and empty nerve baskets. Numerous swollen axons were also present in the cerebellar peduncles.

Discussion

Spotted locoweed growth is cyclic and depends primarily on timing and amount of precipitation. Locoweed seeds are long-lived, and viable seed will persist for many years in soil (Ziemkiewicz and Cronin, 1981). Spotted locoweed often germinates and initiates growth in response to fall or early winter precipitation. The first season after such moisture, locoweed may appear as small, somewhat sparse plants that do not flower the first spring, and which are then dormant during the hot summer (Welsh, 1989). If adequate fall moisture occurs in the second year of their existence, the locoweed population may be much more abundant and most of the locoweed plants will flower in the second year. If spring moisture that second year is not adequate, the plant will die, having been functionally biennial (Welsh, 1989).

In the study area, adequate fall moisture fell during two consecutive years. The locoweed cycle was probably initiated by abundant fall moisture during fall 1996. September and October 1996 had several precipitation events that set records (NOAA, 1996) for daily maximal
Figure 6. Photomicrograph of the cerebellar crus of a locoweed-poisoned horse (A) and a normal horse (B). Notice the swollen neurons with cytoplasmic vacuoles (*). Several swollen axons (arrow) are also present. Hematoxylin- and eosin-stained 4-μm paraffin section: bar = 30 μm.

precipitation (e.g., September 14, 1996, with 3.6 cm of precipitation). We have no record of the density of the spotted locoweed populations during spring 1997, but local observers did not detect dense populations during 1996 (K. Pew, personal communication). Populations were very dense in locations near St. Johns during spring 1998, apparently in response to fall and early winter (September to December 1997) moisture. For example, there were two record-breaking precipitation events during December (December 1: 2.9 cm; December 24: 1 cm). During late winter and spring of 1998, normal precipitation fell only in March; January, February, and April were all drier than normal (NOAA, 1997; 1998). Thus, fall and early winter precipitation was apparently crucial to the very dense spotted locoweed populations noted during spring 1998, even though precipitation was lower than normal from January to April 1998.

Figure 7. Photomicrograph of the thyroid of a locoweed-poisoned horse (A) and a normal horse (B). Insert C is a higher magnification of the follicular epithelium of a locoweed-poisoned horse. Notice the vacuolated follicular epithelium (arrows) and the reduced amounts of colloid. Hematoxylin- and eosin-stained 4-μm paraffin section: bars = 30 μm.
Horses began to eat some spotted locoweed on the second day in the study area. Our observations suggest that horses were selecting green locoweed instead of dormant grasses because locoweed was green. Horses avidly selected the small quantities of green grass that were available, and it appeared that their propensity to eat scarce green forage influenced their locoweed consumption as well. Horses ate relatively little dry grass, even when it was abundant. The preoccupation by horses with green forage suggests that providing green feed might alter horse consumption of spotted locoweed.

The weight loss in horses over the course of the study could be a result of reduced enzymatic digestion, neurological deficits, or both. Swainsonine inhibits digestive enzymes such as sucrase (Pan et al., 1993), and this inhibition likely reduces digestive efficiency and supports weight loss. Pritchard et al. (1990) found that swainsonine toxicity in rats suppressed food and water intake in poisoned animals. Reduced water intake alone could contribute substantially to reduced food intake (Utley et al., 1970). Weight loss may also be related to neurological deficits that cause impaired mobility and inefficient prehension of forage. In contrast, James et al. (1970) found no weight loss in two pen-fed ponies until they had been given locoweed for nearly 80 d.

The enzyme AST did not seem to be as sensitive an index of intoxication in horses as it was in cattle (Stegelmeier et al., 1994), sheep (James et al., 1970), and rodents (Stegelmeier et al., 1995b). Horses may be physiologically different from these other species in that reticular endothelial cells (i.e., macrophages) were not as vacuolated. Horses showed a major reduction in mannosidase activity, indicating the effect of swainsonine as shown in numerous other studies (Stegelmeier et al., 1995a).

Horses seem to be especially prone to eating spotted locoweed and particularly susceptible to its intoxicating effects. Comparative studies of the dose response of cattle and horses to locoweed are lacking, but such studies are clearly needed. Clinically, horses may be susceptible either because they readily accept locoweed when grazing, or because their body systems are more affected than are those of cattle. Rats are much less susceptible than are sheep, cattle, and horses because they require much higher doses to develop neurological lesions (Stegelmeier et al., 1995b). Whatever the reason for their susceptibility, we conclude that horses should not be exposed to substantial spotted locoweed populations.

Cattle, on the other hand, selected mostly dry grass early in the study, and gradually increased the amount of green grass in their diets. Spotted locoweed was a substantial dietary component for cows only during 1 wk in late May, and then consumption by cows declined. Cattle appeared to switch from eating green grass to green forbs before they began to select locoweed in late May. Ralphs et al. (1993) reported that cattle on short-grass prairie rangelands in New Mexico ate whitepoint locoweed (Oxytropis sericea) during spring until warm season grasses began to green up, and then ceased consumption.

Social facilitation may influence grazing cohorts to eat locoweed (Ralphs et al., 1994). Cattle abruptly started eating spotted locoweed on May 24. Grazing by calves was too sporadic to allow consistent bite counts, but we collected limited data on calves when their mothers began to eat spotted locoweed. Calves began eating spotted locoweed on the same day as their dams, and continued to eat about 20% of their bites as locoweed throughout the remainder of the trial. We noted in a previous pen trial with sheep that lambs were not influenced greatly by their locoweed-eating mothers (Pfister and Price, 1996). During this study it appeared that the grazing behavior of the mothers greatly influenced the diet selection of their calves (Mirza and Provenza, 1990; Thorhallsdottir et al., 1990); we have also noted this same maternal influence in consumption of low larkspur by calves (Pfister and Gardner, 1999).

We intended to repeat this study in Arizona in subsequent years; however, spotted locoweed populations have been insufficient for grazing studies. The highly erratic and unpredictable nature of precipitation events in Arizona and surrounding states indicates that livestock problems with locoweed will also be cyclic and sporadic and confined within localized areas. It may be possible to predict outbreaks of locoweed growth through careful observation of precipitation events in localized areas. Nonetheless, no regional model or system of prediction will ever be highly accurate because of the spatial and temporal variability in precipitation over large tracts of rangelands.

Implications

Horses readily selected green locoweed during spring grazing in Arizona, and they were severely poisoned after several weeks of grazing locoweed. Horses that ate locoweed for 7 wk did not recover when removed from locoweed for approximately 1 mo. Cattle, on the other hand, grazed substantial amounts of locoweed only for a brief time and were not intoxicated. Based on limited study, it seems that horses should not be exposed to spotted locoweed during spring. This study raised several additional questions: 1) Does previous exposure enhance subsequent locoweed intake in calves? 2) Will unpoisoned horses eat locoweed when green grass is abundant? and 3) Does supplemental feeding (e.g., green feed) decrease locoweed grazing by horses?

Literature Cited


Locoweed grazing by cattle and horses

2293


