Locoweed Poisoning in the Native Grasslands of China

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Abstract

Locoweeds, including certain species of *Oxytropis* and *Astragalus* that contain swainsonine, are important poisonous plants throughout the world and especially in the vast native grasslands of China. Livestock sustainability and health on the Chinese rangelands are seriously threatened by desertification and locoweed invasion. Enormous economic losses occur every year threatening the local advancement of animal husbandry and endangering the sustainability of the livestock producers in these regions. The purpose of this paper is to review and describe the distribution of locoweed species in China, review information where toxicoses are prevalent, and report current research data on plant–endophyte relationships with locoweed species, poisonings, and relevant management practices, where they exist.

Keywords: Poisonous plants, China, grasslands, locoweed, *Oxytropis*, *Astragalus*, swainsonine, endophyte, *Embellisia oxytropis*, *Undifilum oxytropis*

Introduction

The native grasslands of China are the second largest in the world, comprising more than 400 million hectares (about 40 percent of the land mass of China). The grassland ecosystem in China is massive and ecologically and environmentally important, and it has supported the livestock-based livelihood and survivability of ethnic minorities for centuries. It is currently estimated that about 90 percent of the native grasslands in China has been degraded, with 30 percent in very poor condition (Zhao et al. 2005). Associated with the degradation of grasslands are a loss in productivity; reduced ability to support livestock; a concomitant increase in poisonous plants, rodent, and other pest infestations; and accelerated desertification. The spread of poisonous plants is considered the second-most serious problem after desertification for China's northern grassland region (Zhao et al. 2005). According to previous surveys, the area of native grasslands in northern China where toxic weeds occur at a harmful level is 333 million hectares, with the major threat being locoweed, accounting for about 33 percent of the affected area (figure 1) (Zhao et al. 2005). More recently, the locoweed-infested areas have been expanding (Zhao et al. 2005), and sustainability of livestock production in these critical grassland regions is in peril.

The primary toxic compound in locoweed is the indolizidine alkaloid swainsonine (Molyneux et al. 1989), which is now believed to be produced by the endophyte *Undifilum oxytropis* (Pryor et al. 2009) and which was previously referred to as *Embellisia oxytropis* (Braun et al. 2003, Ralphs et al. 2008, Lu et al. 2009). Interestingly, Broquist et al. (1985) reported production of swainsonine and slaframine (both indolizidine alkaloids with similar biosynthetic

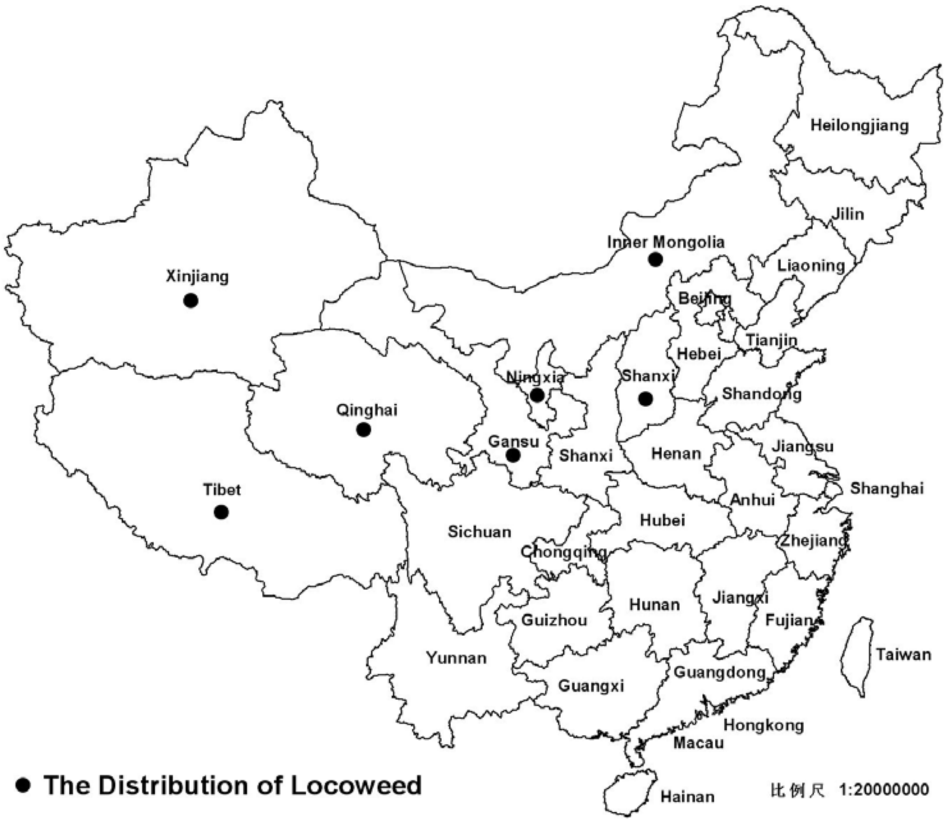

Figure 1. Geographical distribution of locoweeds in China

pathways) production by the non-endophytic fungus *Rhizoctonia leguminicola*, a mold that colonizes certain legumes. In cell culture, *R. leguminicola* has been used to produce swainsonine and slaframine for research applications.

While much research has been conducted in China on locoweeds, endophytes, and swainsonine, more research is required to fully understand the plant–endophyte relationship, determine ways to control the expanding infestation by locoweeds, and develop management guidelines to reduce livestock losses and improve sustainability of this important grassland resource.

Species and Distribution

In China, the locoweeds are mainly distributed in the northwestern and northern regions including Inner Mongolia, Gansu, Ningxia, Qinghai, Xinjiang, Tibet, and Shanxi. According to preliminary surveys (Liu et al. 2010), the area of locoweed infestation in China exceeds 110 million hectares, which accounts for about 2.8 percent of the total grassland area in this northern region. It is reported that 45 species of locoweeds (22 species of *Oxytropis* and 23 species of *Astragalus*) occur in China (Huang et al. 2003). Of these, eight species of *Oxytropis* and three species of *Astragalus* contain swainsonine (table 1).

Livestock Losses Caused by Locoweeds

Clinical signs of locoweed poisoning (swainsonine toxicosis) in livestock in China are the same as those reported in other parts of the world, which include body-weight loss, proprioreceptive deficits, nervousness under stress, cardiovascular disease, reproductive losses, and death (Yang 2002). Substantial livestock losses caused by locoweed have been recorded in China. Over 100,000 sheep were poisoned in Minle County in Gansu from 1953 to 1973; more than 10,000 sheep deaths were caused by *O. ochrocephala* in Haiyuan County in Ningxia from 1976 to 1987; 55,000 animal deaths occurred from locoweed poisoning in the Qinghai Province from 1957 to 1985; and 11,500 animals died as a result of eating *O. sericopetala* near Lhasa in Tibet from 1977 to 1979 (Wang 1999). In horses, reports of reproductive losses are common: there were 16 abortions out of 26 pregnant mares which consumed locoweed, and 75 percent of the mares in another herd in Gonghe County in Qinghai failed to conceive in 1980. Locoweed was believed to be the cause (Zhang and Liu 1994). As the native grasslands of China continue to be over-utilized and degraded, the locoweed areas will expand and livestock poisoning caused by locoweeds will continue to increase.

Table 1. Locoweed species in China, geographical location, and swainsonine content

Species	Geographical location	Swainsonine content (%)
Astragalus hamiensis	Inner Mongolia (Zhong et al. 2007)	0.005 (Liu et al. 2009)
Astragalus strictus	Tibet (Wang et al. 2007)	0.004 (Liu et al. 2009)
Astragalus variabilis	Inner Mongolia, Gansu, Ningxia (Lu et al. 2006, Zhao et al. 2003)	0.010 (Liu et al. 2009)
Oxytropis deflexa	Qinghai (Zhao et al. 2003)	0.013 (Liu et al. 2009)
Oxytropis falcata	Qinghai (Zhao et al. 2003)	not quantified (Huo et al. 2008)
Oxytropis glabra	Inner Mongolia, Gansu, Xinjiang, Tibet, Shanxi (Lu et al. 2006, Wang et al. 2007, Zhao et al. 2003)	0.008 (Liu et al. 2009)
Oxytropis glacialis	Tibet (Wang et al. 2007)	0.018 (Liu et al. 2009)
Oxytropis kansuensis	Gansu, Qinghai, Tibet (Wang et al. 2007, Zhao et al. 2003)	0.015 (Liu et al. 2009)
Oxytropis latibracteata	Qinghai (Zhao et al. 2003)	0.010 (Liu et al. 2009)
Oxytropisochrocephala	Inner Mongolia, Gansu, Ningxia, Qinghai, Tibet (Lu et al. 2006, Wang et al. 2007, Zhao et al. 2003)	0.015 (Liu et al. 2009)
Oxytropis sericopetala	Tibet (Wang et al. 2007)	not quantified (Yu et al. 2006)

Management of Locoweeds and Intoxication

Locoweeds can be temporarily controlled by physically pulling or burning the plants in situ; however, because it has a large tap root, burning does not completely kill the plant (Fan et al. 2006). Herbicides such as 2,4-D can be used over larger areas to control locoweeds; however, this is costly and it will kill other desirable forage plants. There are no herbicides that specifically target *Oxytropis* or *Astragalus* species (Wu et al. 2001). Herbicides may also contaminate the air and water, thereby causing environmental concerns, or plants may develop resistance. Moreover, some herbicides may kill only the top growth, allowing regeneration from the roots as well as germination of seed reserves in the soil (Fan et al. 2006). Seed reserves in the soil are abundant and seedlings will re-establish stands of locoweed when environmental conditions permit. Long-term control must be multidimensional and should include range practices to manage competitive grasses to prevent reinvasion once locoweeds are suppressed.

In China, various methods of treatment have been utilized by livestock producers (Zhao et al. 2005). Livestock should first be removed from locoweed-infested sites. Furthermore, Zhao et al. (1999) reported that the mixture of vinegar residue and coarse flour could detoxify the sheep poisoned with *O. glabra* (figure 2). Chang et al. (2007) reported that "Fengcaolin bolus" could relieve suffering in sheep poisoned with *O. ochrocephala*. Toxicity and the timing when symptoms of toxicity became evident appeared to be delayed, but it did not prevent injury of the tissues and organs (liver, kidney, and muscle) by the toxins; thus it simply delayed the onset of symptoms in sheep and did not lead to complete detoxification.

Figure 2. *Oxytropis glabra*, one of the locoweed species infesting large areas of the grasslands of northern China.

The concept of vaccination against locoweed poisoning is attractive; however, practical immunization against small-molecular-weight plant toxins, although successful, has been limited (Than et al. 1998, Lee et al. 2003). Development of swainsonine-protein conjugates for immunologic response has been reported (Tong et al. 2001a).

A bacterium strain that can degrade swainsonine has been isolated and cultured (Zhao 2008). Efforts are under way to develop a method for colonizing

Figure 3. Grasslands of northern China extensively infested with the locoweed *Oxytropis glabra*.

this strain in the rumen to precondition livestock to reduce locoweed poisoning.

Management for the control of locoweeds should consider protecting the native grassland ecosystems and conserving ecological balance to reduce locoweed infestation (figure 3). Management strategies also should include methods to restore degraded grasslands to support a sustainable development of animal husbandry. Management to achieve these goals requires a long treatment cycle. In one strategy, highly competitive forage plants were selected and sown in the locoweed-infested areas to reduce locoweed density and thus reduce risks of livestock poisoning (Zhao et al. 2008); however, this strategy has not yet been applied on a large scale in locoweed-infested areas of China.

Swainsonine in Locoweeds

In China, swainsonine was first isolated from *O. ochrocephala* by Cao et al. (1989), who also confirmed that swainsonine inhibits α-mannosidase in livestock, resulting in locoism. Subsequently, swainsonine was also isolated from *A. variabilis* by Huang et al. (1992), *A. strictus* by Zhao et al. (1993), *O. kansuensis* by Tong et al. (2001b), *O. glacialis* in Tibet by Tan et al. (2002), *O. glabra* by Ge et al. (2003), and *O.falcata* by Huo et al. (2008). The swainsonine content of *O. kansuensis*, *A. variabilis*, *A. strictus*, *O. sericopetala*, and *O. glacialis* was analyzed and semi-quantified by thin-layer chromatography (TLC) (Tong et al. 2003). Most recently, swainsonine content of *A. variabilis*, *A. strictus*, *A. hamiensis*, *O. glabra*, *O. kansuensis*, *O. ochrocephala*, *O. glacialis*, *O. deflexa*, and *O.latibracteata* was determined by Liu et al. (2009). These results showed that the mean swainsonine content of *O. kansuensis* at 0.148 mg/g was the highest of the Chinese species and that of *A. hamiensis* at 0.044 mg/g was the lowest among these species. The average swainsonine content at flowering was 0.139 mg/g, which was the highest among all phenological stages, while the average content in flowers was 0.162 mg/g, which was the highest among all plant parts. This research also demonstrated that swainsonine content of locoweeds increased with elevation.

Swainsonine in Endophytes

Thus far, 10 strains of endophyte have been isolated from *O. glabra* in Inner Mongolia by Lu et al. (2009). Forty-two strains of endophyte have been isolated from *A. variabilis, A. strictus, O. glabra, O. kansuensis, O. ochrocephala, O. glacialis*, *and O. sericopetala.* Of these, 11 strains produce swainsonine and have been classified as *Undifilum oxytropis* according to both morphological characteristic and the 5.8SrDNA/ITS sequence analysis (Yu 2009). PCR-RFLP analysis of intergenic spacer (IGS) region for those 11 endophyte strains showed that the interspecific or intraspecific variations were present among the endophytes from different locoweed species (Yu et al. 2011).

Prospects for Locoweed Utilization

Despite its toxic properties, *Oxytropis* and *Astragalus* have potential as forage resources, being palatable and rich in crude protein. A deep-rooted legume, locoweed is drought tolerant and cold resistant, and it has a low nutritional requirement that enables it to grow under harsh environmental conditions. These characteristics make it very useful for stabilizing moving sands and conserving soil and water. More research is needed to understand how locoweeds might be managed as forage in arid and semi-arid grasslands in China. The relationship between the endophyte, swainsonine, and the plant must be well understood before much progress can be made to utilize locoweeds safely for livestock forage.

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References

Broquist, H.P., P.S. Mason, B. Wickwire, et al. 1985. Swainsonine production in the mold *Rhizoctonia leguminicola*. *In* A.A. Seawright, M.P. Hegarty, L.F. James, and R.F. Keeler, eds., Plant Toxicology, pp. 301-308. Queensland Poisonous Plants Committee, Yeerongpilly, Australia.

Braun, K., J. Romero, D. Liddell, and R. Creamer. 2003. Production of swainsonine by fungal endophytes of locoweed. *Mycology Research* 107:980-988.

Cao, G.R., S.J. Li, D.X. Duan, et al. 1989. The isolation and identification of toxic components from *Oxytropis ochrocephala. Journal of the Northwest Sci-Tech University of Agriculture and Forestry* 17:1-6.

Chang, J.J., C.H. Mo, B.Y. Zhao, et al. 2007. Trial of Fengcaoling bolus in preventing sheep suffering from *Oxytropis ochrantha* toxicity. *Pratacultural Science* 24:76-78.

Fan, Z.F., Y.Y. Fan, B.Y. Zhao, et al. 2006. Progress in research on prevention of poisoning from locoweed. *Heilongjiang Animal Science and Veterinary Medicine* 1:24-25.

Ge, P.B., B.Y. Zhao, D.W. Tong, et al. 2003. Extraction and fractionation and identification of swainsonine on structure from *Oxytropis glabra. Chinese Agricultural Science Bulletin* 19:1-4.

Huang, Y.D., Z.G. Xiao, J.C. Meng, and F.K. Kong. 1992. The separation and analysis of toxic components from *Astragalus variabilis*. *Journal of Traditional Chinese Veterinary Medicine* 4:3-6.

Huang, Y.Q., E.Y. Zhang, and W.F. Pan. 2003. Current status of locoweed toxicity. *Shandong Science* 16:34-39.

Huo, X.H., B.Y. Zhao, J.J. Wang, et al. 2008. Preliminary chemical test of *Oxytropis falcata* Bunge and alkaloids analysis by TLC. *Acta Agriculture Boreali-Occidentalis Sinica* 17:24-28.

Lee, S.T., B.L. Stegelmeier, K.E. Panter, et al. 2003. Evaluation of vaccination against methyllycaconitine toxicity in mice. *Journal of Animal Science* 81:232-238.

Liu, Z.Y., Z.X. Wang, B.Y. Zhao, et al. 2009. The study on dynamic variation law of swainsonine from major locoweeds in China. Proceedings of the Chinese Association of Veternary Internal Medicine (CAVIM), pp. 556-564. Qingdao, China.

Liu, L., Y. Feng, Z.H. Jia, and B.Y. Zhao. 2010. Research progress on development and utilization of locoweed in China. *Acta Ecology and Animal Domestication* 31:102-105.

Lu, P., M.L. Zhao, G.D. Han, et al. 2006. The locoweed in Inner Mongolia and research progress. *Chinese Journal of Grassland* 28:63-68.

Lu, P., D. Child, M.L. Zhao, et al. 2009. Culture and identification of endophytic fungi from *Oxytropis grabra* DC. *Acta Ecology Sinica* 29:53-58.

Molyneux, R.J., L.F. James, K.E. Panter, and M.H. Ralphs. 1989. The occurrence and detection of swainsonine in locoweeds. *In* L.F. James, A. Elbein, R.J. Molyneux, and C.D. Warren, eds., Swainsonine and Related Glycosidate Inhibitors, pp. 100-117. Iowa State University Press, Ames, IA.

Pryor, B.M., R. Creamer, and R.A. Shoemaker. 2009. *Undifilum*, a new genus for endophytic *Embellisia oxytropis* and parasitic *Helminth osporium bornmuelleri* on legumes. *Botany* 87:178-194.

Ralphs, M.H., R. Creamer, D. Baucom, et al. 2008. Relationship between the endophyte *Embellisia* spp. and the toxic alkaloid swainsonine in major locoweed species (*Astragalus* and *Oxytropis*). *Journal of Chemical Ecology* 34:32-38.

Tan, Y.Y., J.H. Wang, Q.F. Li, et al. 2002. Extraction and separation of alkaloids from glacial crazyweed (*Oxytropis glacialis*). *Chinese Journal of Animal and Veterinary Sciences* 33:352-355.

Than, K.A., Y. Cao, A. Michalewicz, and J.A. Edgar. 1998. Development of a vaccine against annual ryegrass toxicity. *In* T. Garland and C.A. Barr, eds., Toxic Plants and Other Natural Toxicants, pp. 165-168. CABI Publishing, Wallingford, U.K.

Tong, D.W., G.R. Cao, and D.L. Cheng. 2001a. Study on synthesis of swainsonine-BSA. *Journal of the Northwest Sci-Tech University of Agriculture and Forestry* 29:9-12.

Tong, D.W., G.R. Cao, and X.J. Zhao. 2001b. Isolation and identification of swainsonine from *Oxytropis kansuensis* Bunge. *Acta Agriculture Boreali-occidentalis Sinica* 10:6-8.

Tong, D.W., G.R. Cao, G.X. Geng, et al. 2003. Determination on content of swainsonine in five locoweeds. *Chinese Journal of Veterinary Science* 23:183-184.

Wang, J.H. 1999. Harmfulness and treatment of locoweed in China. Proceedings of Science and Technology for Social and Economic Development: Toward the 21st Century, p. 216. 1999 CAST Annual Meeting, Hangzhou, China.

Wang, J.J., B.Y. Zhao, Z.F. Fan, and Silang Yuzhen. 2007. Distrbution, harmfulness and treatment of locoweed in Tibet. *Prataculture & Animal Husbandry* 6:36-40.

Wu, D., J.H. Wang., and Y.H. Wang. 2001. Studies on the prevention or killing off and utilization of China locoweed. *Chinese Qinghai Journal of Animal and Veterinary Sciences* 31:29-30.

Yang, X.P. 2002. Clinical symptoms of toxicosis in animals by crazyweed. *Journal of the Wuhang Institute of Science and Technology* 15:25-28.

Yu, Y.T. 2009. Isolation, identification and genetic polymorphism of swainsonine-producing fungal endophytes from locoweeds in China. Northwest Agriculture and Forestry University, Yangling, Shaanxi, China. Ph.D. thesis.

Yu, Y.T., Z.B. Liu, X.H. Zhao, et al. 2006. Purification and identification of swainsonine in the *Oxytropis serioopetala. Animal Husbandry and Veterinary Medicine* 38:1-3.

Yu, Y.T., Q.M. Zhao, J.N. Wang, et al. 2011. Swainsonine-producing fungal endophytes from major locoweed species in China. *Toxicon* 56:330-338.

Zhang, J., and X.C. Liu. 1994. Survey and progress of studies on poisoning from locoweed. *Journal of Traditional Chinese Veterinary Medicine* 1:46-48.

Zhao, B.Y., G.R. Cao, and S.J. Li. 1993. The separation and analysis of toxic components from *Astragalus strictus*. *Chinese Journal of Veterinary Science and Technology* 23:20-21.

Zhao, B.Y., D.W. Tong, P.B. Ge, et al. 2003. Locoweed harm investigation in the west grassland of China. *Chinese Journal of Grassland* 25:65-68.

Zhao, B.Y., Y.Y. Fan, Z.F. Fan, et al. 2005. Harmfulness of locoweed and controlling of animal poisoning in Chinese western grassland. *Journal of Health Toxicology* 19:310-311.

Zhao, B.Y., Z.Y. Liu, X.P. Wang, et al. 2008. Damage and control of poisonous-weeds in Chinese western grassland. *Scientia Agriculture Sinica* 41:3094-3103.

Zhao, Q.E., Y.G. Liu, and T.Y. Liu. 1999. The first exploration for treating sheep poisoning from *Oxytropis glabra. Animal Toxicology* 14:14.

Zhao, X.H. 2008. Isolation and identification of swainsonine degrading bacteria and degradation character. Northwest Agriculture and Forestry University, Yangling, Shaanxi, China. Ph.D. thesis.

Zhong, Y.S., B.G. Song, J.G. Yu, et al. 2007. Survey of major poisonous plants and livestocks poisoning in Ejin Banner. *Progress in Veterinary Medicine* 28:113-116.

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