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ORIGINAL RESEARCH

Presence of L-Canavanine in *Hedysarum alpinum* Seeds and Its Potential Role in the Death of Chris McCandless

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Objective.—For the past 2 decades there has been vigorous disagreement over the purported toxicity of *Hedysarum alpinum* seeds, and whether the consumption of such seeds was a factor in the 1992 death of Chris McCandless, the subject of the book *Into the Wild*. Our objective was to confirm or disprove the presence of L-canavanine (a nonprotein amino acid known to induce systemic lupuslike symptoms in humans) in *H alpinum* seeds.

Methods.—Liquid chromatography–tandem mass spectrometry analysis of *H alpinum* seeds was performed.

Results.—Our analysis confirmed the presence of L-canavanine in *H alpinum* seeds and demonstrated that it is a significant component of the seeds, with a concentration of 1.2% (weight/weight), roughly half of that found in *Canavalia ensiformis*.

Conclusions.—The data led us to conclude it is highly likely that the consumption of *H alpinum* seeds contributed to the death of Chris McCandless.

Key words: Hedysarum alpinum, Hedysarum mackenzii, L-canavanine, ODAP, McCandless, Into the Wild

Introduction

Twenty-four-year-old Christopher McCandless died in the Alaska wilderness on August 19, 1992, after subsisting for 114 days by hunting game and foraging for edible plants. Before going to Alaska he weighed 140 pounds. An autopsy performed approximately 3 weeks after his death determined that his remains weighed 67 pounds and lacked discernible subcutaneous fat. Starvation was cited as the probable cause of death. A diary, additional documents written on birch bark, and photographs recovered with McCandless' body indicated that starting on June 24, 1992, the roots of *Hedysarum alpinum* (L [Eskimo potato, wild potato, Alaska carrot]) became a staple of his meager diet. His diary was written on blank pages in the back of *Tanaina Plantlore: Dena'ina K'et'una*,[1] an ethnobotany of the indigenous Dena'ina people of Southcentral Alaska, which McCandless relied on to identify edible plants.

The Dena'ina harvest *H alpinum* roots when the ground thaws in the spring, and again in the autumn after the first frosts, because the roots are juicy and tender during those periods. However, the Dena'ina do not dig *H alpinum* roots during the high summer months because they become dry and tough.[1] McCandless' diary indicates that he stopped eating *H alpinum* roots on July 7, presumably because the advance of summer rendered them unpalatable. On July 14, he began harvesting and eating the seeds of *H alpinum* to replace this major component of his diet (Figure 1). But on July 30, McCandless wrote in his diary, ominously, "EXTREMELY WEAK. FAULT OF POT[ATO] SEED. MUCH TROUBLE JUST TO STAND UP. STARVING. GREAT JEOPARDY." He died 20 days later.[2]

All parts of *H alpinum* have been thought to be nontoxic,[3] and the roots of *H alpinum* are specifically described as edible by Kari in *Tanaina Plantlore*.[1] The *H alpinum* roots are also described as edible in a popular guide to Alaskan wildflowers.[4] Significantly, however, we could find no reports of the Dena'ina or any other Alaskan Natives using *H alpinum* seeds as food, even during times of acute food shortage. Based on this conspicuous absence in the detailed ethnobotanical history of indigenous Alaskans, and based even more on the alarming references to *H alpinum* seeds in

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Figure 1. *Hedysarum alpinum* seeds harvested by Chris McCandless for food on July 18, 1992, in a 1-gallon Ziploc bag. Estimated dry weight 600 g.

McCandless' diary, Krakauer speculated in *Into the Wild* [2] (his widely read 1996 book about McCandless) that *H alpinum* seeds contain swainsonine, a toxic alkaloid. According to Krakauer's hypothesis, the swainsonine in the seeds incapacitated McCandless to such a degree that it became impossible for him to hike out of the bush or hunt effectively, resulting in his death by starvation.

Krakauer's hypothesis was disputed with thin-layer chromatography (TLC) analyses and a cytotoxicity assay undertaken by Treadwell and Clausen,[3] who found "no chemical basis for toxicity" in the seeds of *H alpinum* or in a closely related species, *Hedysarum mackenzii* (Richardson [wild sweet pea, bear root]). The findings of Treadwell and Clausen were subsequently disputed in a hypothesis advanced by Ronald Hamilton,[5] positing that *H alpinum* seeds and *H mackenzii* seeds were indeed toxic, and the toxic agent was not an alkaloid, but rather the nonprotein amino acid beta-N-oxalyl-L-alpha-beta diaminoproprionic acid, commonly referred to as L-β-ODAP or simply ODAP, which is a constituent of seeds in certain species of Fabaceae. Hamilton further conjectured that L-β-ODAP—a neurotoxin identified in 1964 that causes lathyrism, a degenerative disease of the nervous system—played a central role in the death of McCandless.[5,6]

In 2004, TLC analyses of *H alpinum* seeds and *H mackenzii* seeds revealed prominent ninhydrin-positive spots with mobility essentially identical to that of L-β-ODAP (J. Southard and W. Gruber, unpublished data, 2004). However, the relatively low resolving power of the separation method precluded the positive identification of the seed component as L-β-ODAP. In 2013, seeking more definitive results, we conducted analyses employing reverse-phase high-pressure liquid chromatography and liquid chromatography–mass spectrometry (LC-MS). These analyses detected a prominent *H alpinum* seed component with the expected molar mass (MW 176) for L-β-ODAP. However, subsequent liquid chromatography–tandem mass spectrometry (LC-MS/MS) analysis showed that the fragmentation-ion pattern for this component did not match that of L-β-ODAP.

These analyses nevertheless suggested the possibility that a significant concentration of a compound structurally similar to L-β-ODAP (MW 176.13) might be present in the seeds. An exhaustive review of the literature about nonprotein amino acids known to be deleterious to human health revealed that, in 1960, Birdsong et al[7] determined by paper chromatography–trisodium pentacyanoammonioferrate colorimetric analysis that the nonprotein amino acid L-canavanine (MW 176.17) is a constituent of *H alpinum* seeds.[8] L-canavanine is a toxic antimetabolite stored in the seeds of many leguminous species to ward off predators.[9]

Figure 2 shows the structures of swainsonine, L-β-ODAP, and L-canavanine, all implicated as possible toxic compounds in *H alpinum*. Of these, L-canavanine is the only one with published evidence showing it to be present in *H alpinum* seeds. Given the controversy surrounding the toxicity of these seeds, we believed it would be valuable to reevaluate the presence of this known toxin. Methods for analysis of plant constituents have advanced significantly since the time of the original

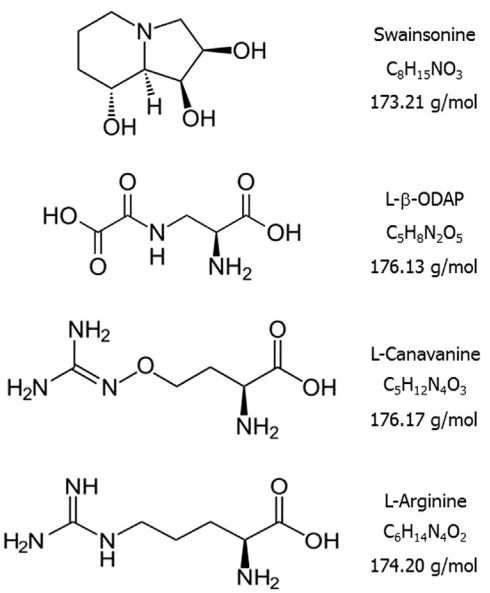

Figure 2. Compounds presumed or known to be present in *Hedysarum alpinum.* The alkaloid swainsonine and the amino acid beta-N-oxalyl-L-alpha-beta diaminoproprionic acid (L-β-ODAP) have been suggested as possible toxic constituents but their presence has not been demonstrated. L-Canavanine, shown to be present in seeds, is an antimetabolite that can replace L-arginine during protein synthesis.