Accumulation of cadmium and selected elements in flax seed grown on a calcareous soil

J.T. MORAGHAN
North Dakota State University, Fargo, ND 58105, USA

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Abstract

Seed of flax (Linum usitatissimum L.) grown on calcareous and neutral soils sometimes accumulates relatively high concentrations of Cd. The influence of a post-flowering application of NH₄NO₃ (115 mg N kg⁻¹), CdSO₄ (1 mg Cd kg⁻¹), FeEDDHA (2 mg Fe kg⁻¹), NaH₂PO₄ (120 mg P kg⁻¹) and ZnSO₄ (8 mg Zn kg⁻¹) on seed accumulation of Cd, Fe, N, Mn, P and Zn by flax grown on a Calciaquoll was studied in two experiments under greenhouse conditions. Seed yields were increased by the N and Zn treatments, and the N × Zn interaction was positive. Zinc deficiency delayed flowering and boll formation by up to 20 days and reduced seed size. In the absence of added Cd, seed accumulated up to 0.33 mg Cd kg⁻¹. This Cd accumulation was reduced by approximately 50 and 17% by added Zn and Fe, respectively, but was little affected by P fertilizer and post-flowering N stress. In the presence of added Cd, seed Cd exceeded 3.3 mg Cd kg⁻¹, and the antagonistic effects of Fe and Zn on seed Cd were absent. Seed N, P, Fe and Zn concentrations were increased on average by 10, 45, 31 and 97% by the N, P, Fe and Zn fertilizer treatments, respectively. FeEDDHA reduced seed Mn concentration by approximately 58%. However, seed Mn concentration was much less than that found in vegetative tissue at flowering. Soil-applied Zn may reduce seed Cd concentration in flax under field conditions, and may increase marketability of flax for food use.

Introduction

Oilseed flax, commonly called linseed outside North America, is often grown in Canada and in the USA on neutral and calcareous soils. The soils are often low in available N and P, and to a lesser extent Zn and Fe. The use of flax seed as a human food source is currently of considerable interest. Based on the contents of a recent, comprehensive literature review on the mineral nutrition of flax (Hocking et al., 1988), little is known about the accumulation in flax seed of elements with variable or low phloem mobility such as Fe, Zn, Mn and presumably Cd. Mobility of nutrients in phloem liquid is considered to be of major importance for their accumulation in seed (Welch, 1986).

Flax grown on calcareous soils is susceptible to Zn deficiency, and readily accumulates Mn in vegetative tissue (Moraghan, 1978). This Mn accumulation is markedly reduced by application of FeEDDHA (Moraghan and Freeman, 1978). Flax roots in calcareous soils are able to change the rhizosphere environment and increase the solubility of soil nutrients. For instance, flax grown on a calcareous soil without added Fe
accumulated twice the level of 'readily soluble' and 'weakly adsorbed' Mn in the rhizosphere than corn, wheat, oat, barley, tomato, soybean and sunflower (Warden and Reisenauer, 1991).

A regional farmer advised the author in 1988 that some North American flax seed exported to Europe for bread manufacturing contained relatively high and unacceptable Cd levels (>0.3 mg kg⁻¹). This Cd accumulation was unexpected, since the flax was grown on a non-sludge-treated calcareous soil, and liming acid soils to pH 6.5–7 is generally found to decrease the bioavailability of soil Cd (Alloway and Jackson, 1991). Crops differ greatly in their ability to accumulate Cd; Cd accumulation usually is greater in leafy vegetables than in seed or root crops (Alloway et al., 1990). However, sunflower seed raised in this region and in other parts of the world also accumulates Cd (Stoewsand et al., 1986). Recent German research has confirmed that flax seed accumulates relatively high levels of Cd; both geographical location and flax variety influenced its accumulation (Marquard et al., 1990).

Phosphorus (Logan and Feltz, 1985) and Zn (Haghiri, 1974; Smilde et al., 1992) may reduce the uptake or translocation of Cd in plants. FeEDDHA applied to calcareous soils may also influence the uptake of Cd, since flax grown on soils low in available Fe exhibits a strong Strategy-I Fe-deficiency-stress response which is suppressed by the chelate (Moraghan and Freeman, 1978). Information is sparse about factors influencing the accumulation of Fe and Mn in flax seed.

Nitrogen stress is sometimes observed in older leaves in commercial flax fields during the grain-formation stage. Nitrogen stress during the post-flowering period intensifies leaf senescence and is known to increase the translocation to grain of Cu (Loneragan et al., 1980) and possibly Zn (Hill, 1980). Nitrogen stress reportedly also increases the translocation of Zn from root Zn-protein complexes to above-soil plant parts (Ozanne, 1955). Whether post-flowering N stress increases Cd accumulation by flax seed is apparently not known.

The objective of these greenhouse investigations was to determine the influence of Zn, Cd, P and Fe compounds, and post-flowering N stress, on the elemental composition of flax seed grown on a calcareous soil.

Materials and methods

General

The soil was collected from the 0- to 15-cm depth of a Wheatville loam (coarse-silty over clayey, frigid, Aeric Calciaquoll). Selected properties of the air-dried soil were the following: pH = 8.3; inorganic C = 6.2 g kg⁻¹; NO₃⁻-N = 20 mg kg⁻¹; DTPA-extractable Cd = 0.15 mg kg⁻¹; DTPA-extractable Fe = 6 mg kg⁻¹; DTPA-extractable Mn = 5 mg kg⁻¹; DTPA-extractable Zn = 0.3 mg kg⁻¹; and NaHCO₃-extractable P = 10 mg kg⁻¹.

Each experimental unit consisted of 4,500 g of air-dried soil. Pots were watered periodically with distilled, deionized H₂O to the approximate field capacity to avoid plant wilting. The watering weights were adjusted periodically to compensate for plant growth. Pots in each replication were placed on individual moveable tables. Tables and pots within each replication were rotated daily to reduce greenhouse variability. Greenhouse temperatures were generally maintained between 18 and 25°C.

All fertilizers, with the exception of FeEDDHA and post-planting applications of N fertilizer, were mixed with the air-dried soil in a twin-shell blender. The required quantity of FeEDDHA, dissolved in 50 mL of deionized water, was added to the soil surface prior to the initial watering to field capacity. Post-planting applications of N fertilizer, increments of 10 or 15 mg NH₄NO₃-N kg⁻¹, were added periodically before regular waterings.

Thirty seeds of 'Omega' flax, subsequently thinned to give 11 plants pot⁻¹, were planted in each pot. Omega, which has a golden-colored seed, is considered especially suitable for the food industry. Mature bolls (capsules) were harvested whenever pedicels turned brown. Seed was separated by crushing bolls contained in polyethylene bags with wooden rollers and removing chaff by vacuum. Seed was dried at 70°C for 24 hours. The seed was not ground before chemical analysis in order to reduce the likelihood of contamination.

Experiment 1

The treatments were eight in number and consisted of two post-flowering N regimes in factori-