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Selenium content of Finnish oats in 1997–1999: effect of cultivars and cultivation techniques

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Se-supplemented fertilization is the main factor affecting the selenium (Se) contents of cereals in Finland. Soil and climatic conditions determine the activity of selenate added to soils and bioavailability to plants. In the present study the Se contents and its variation in Finnish oats, the differences between oat cultivars and cultivation techniques were examined. The selenium (Se) contents of oats (*Avena sativa* L.) in Finland were examined during 1997–1999 in 3 types of trial: official variety, organic cultivation variety and organic vs. conventional cultivation trials. Farm samples were also examined. The mean Se contents of oats in official variety trials were 0.110, 0.120 and 0.160 mg kg^{-1} dry weight (dw) range 0.016–0.460 mg kg^{-1}dw in 1997–1999, respectively. The mean Se contents in farm samples were 0.050 and 0.130 mg kg^{-1}dw in 1998 and 1999, ranging between < 0.010 and 0.330 mg kg^{-1} dw. Considerable regional and seasonal variations existed. The Se contents of oats were significantly higher in 1999 probably due to the combined effect of not increased fertilizer level (from 6 to 10 mg Se kg^{-1} fertilizer) and very low precipitation in 1999. The Se contents of oats were significantly lower in organic cultivation, due to the absence of Se-supplemented fertilization. Significant ($P < 0.001$) cultivar differences were detected in official variety trials. The cultivars Veli and Leila showed higher levels of Se.

Key words: *Avena sativa*, oats, selenium, cereals, cultivars, organic farming, fertilizers

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Introduction

Oats (*Avena sativa* L.) have recently increased more importance as a functional cereal food due to beneficial physiological properties. Oat bran decreases serum cholesterol (Anderson et al. 1984) and blood glucose levels (Wood et al. 1990). Oats have also been shown to be suitable to dietary therapy for coeliac disease patients (Janatuinen et al. 1996 Hardman et al. 1997, Reunala et al. 1998). In animal nutrition oats serve as good quality feed for horses, hens, broilers, sheep and milking cows. The importance of selenium (Se) in animal and human nutrition is well known. Oat cultivation in Finland has gradually increased, attaining a level of 450 000 ha in 2002. Currently, oat cultivars most generally used in Finland are Veli, Aarre, Roope and Leila, corresponding to 57% of oat cultivation (KTTK 2002).

Se is available to plants in inorganic form as selenate and selenite and organic form (Adriano 1986). Many factors influence the form of Se present in soils: soil pH, soil type and texture, presence of ions, precipitation and climatic conditions (Gissel-Nielssen 1971, Adriano 1986, Gissel-Nielssen 1988, Vuori et al. 1989, Mikkelsen and Wan 1990, Yläranta 1993). For geochemical and climatic reasons soils in Finland are deficient in available Se (Koljonen 1975, Sippola 1979, Sillanpää and Jansson 1992). Typical features of agricultural soils in Finland include their relatively strong natural acidity (mean soil pH about 5.75; Erviö et al. 1990, Mäkelä-Kurtto and Sippola 2002), low electrical conductivities and $CaCO_3$ equivalents, and high organic carbon content (Sillanpää and Jansson 1992). Under conditions prevailing in Finland selenate is easily reduced selenite or even more reduced forms and strongly bound to iron and aluminium oxides, and organic matter. Only about 4% of the total Se supply is in soluble (hot-water-extractable) form (Yläranta 1993). The mean hot-water-extractable Se content in agricultural soils in 1998 was 0.010 ± 0.005 mg l^{-1} (Mäkelä-Kurtto and Sippola 2002).

The first attempt to improve Finnish Se-situation was made in 1960s when domestic animal feeds were supplemented with Se. During the 1970s the Se content of domestic agricultural products was still found to be exceptionally low and the Se intake of Finns was only about 25–30 µg per day (Varo et al. 1980a). In 1984 Se supplementation of compound fertilizers was started. The original target of Se supplementation of fertilizers was to raise the Se content of cereal grains to about 0.1 mg kg^{-1} and thus increase the Se intake in the population. It was also seen that other domestic food and feed items would be affected. During the intervention the Se supplementation level has been revised twice, the latest revision being from 6 to 10 mg kg^{-1} fertilizer in 1998 (Eurola and Hietaniemi 2000). However, Se supplementation does not affect organic cultivation where the use of compound, inorganic fertilizers is not allowed.

The aims of the present study were to determine the Se contents and its variation in Finnish oats, examine the differences between oat cultivars and compare organic and conventional cultivation techniques with respect to Se.

Material and methods

Oat field trials

Two types of trial were performed: official variety trials (1997–1999) in 8–10 locations throughout Finland and organic cultivation trials (1997–1998). The cultivars in official variety trials were Belinda, Kolbu, Leila, Roope, Salo and Veli. The organic cultivation trials included organic cultivation variety trials in 7 locations and comparison of organic and conventional cultivation in 6 locations. The cultivars were Aarre, Katri, Kolbu, Leila, Puhti, Roope, Veli and Yty. Organic and conventional cultivation were compared using 2 cultivars Veli and Puhti. In organic cultivation the preceding crop was clover to improve the nitrogen status of the soil. At Ruukki and

Jokioinen animal manure was also used. More detailed information on the trials were published previously (Järvi et al. 2000). In general, the growing season for 1998 was rainy and cool and for 1997 and 1999 dry and warm.

Farm samples

Oat farm samples were received from the Plant Production Inspection Centre Grain Laboratory which annually collects samples from farmers for the Grain Quality Monitoring Project.

Sample pretreatment and chemical analysis

The grain samples were dried to a moisture content of < 14%. The samples were sorted with a 2-mm sieve and hulled with a BT 459, hulling machine using air pressure at Boreal Plant Breeding Ltd. Broken groats were discarded. Oat groats were milled with a falling-number hammer mill, using a 1.0-mm sieve and stored in the freezer until analysis. The farm samples were only milled, not sieved or hulled.

Dry matter content as dry weight (dw) was determined gravimetrically after oven-drying the sample for 2 h at 130 ± 2°C. The precence of Se was determined with an electrothermal atomic absorption method (Kumpulainen et al. 1983). The oat samples were digested in a mixture of concentrated HNO_3, $HClO_4$ and H_2SO_4, Se(VI) was reduced to Se(IV) with HCl and extracted into methylisobutylketone (MIBK) and measured with a Varian SpetrAA 400 graphite furnace atomic absorption spectrometer. The analytical method is accredited and the samples analysed as duplicates. The reference material and blank were included in each digestion batch and measured with the samples. The Se concentration in ARC/CL wheat flour was 0.055 ± 0.006 mg kg^{-1}, the certified value being 0.055 ± 0.14 mg kg^{-1} dw.

Statistical analysis

The statistical methods used were described previously (Eurola et al. 2003). Before performing the analyses, assumptions of group variances were checked in Box-Cox diagnostic plots, normality assumptions of errors was assessed with stem-and-leaf display and normal probability plot. The differences between the cultivars in variety and organic cultivation trials were analyzed using mixed linear models. The year, location and trial were analyzed as a random factor and cultivars as the fixed factor (Öfversten and Nikander 1996). The effects of farming systems (organic vs. conventional), cultivars (Veli and puhti) and their interactions were determined by analyses of variance according to the split plot design. The farming system and cultivars were analyzed as the fixed and location and year as the random factor. All analyses were performed using the SAS mixed, univariate and g-plot procedures.

Results and discussion

The mean Se contents of oats in official variety trials were 0.110, 0.120 and 0.160 mg kg^{-1} dw (range 0.016–0.460 mg kg^{-1}dw) in 1997–1999, respectively. Considerable regional and seasonal variations existed (Table 1), due to differing soil and weather conditions and fertilization, which is the most important single factor affecting Se concentrations of oats and other cereals in Finland. The highest Se concentrations were found in oats grown in fine sandy soils in Mikkeli and clay soil in 1999 in Vihti, while the lowest concentrations occurred in mould and coarse silty soils in the northern research stations Ylistaro and Ruukki. Generally, the Se concentrations of agricultural soils in Finland tend to decrease northwards. In southern Finland clay soils with higher Se contents predominate and peat and organic soils are more abundant in northern Finland (Sippola 1979, Mäkelä-Kurtto

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and Sippola 2002). However, the highest total soil Se concentrations in Finland have been found in clay and organogenic soils, the lowest in coarse mineral soils. Se in the clay and organogenic soils is strongly bound to the soil constituents (Yläranta 1985). In Yläranta's studies (1985), 4.6% of the total Se content was extracted from coarse mineral soils into hot water, which was over 20% more than extraction from clay or organogenic soils. Se applied as selenate may remain in the form available to plants in coarse mineral soils longer where the surface area is smaller and the soil more aerated. Selenate may also leach out of the root zone more easily from coarse soil types.

Generally, the Se contents of oats were significantly higher in 1999; the main reason is the effect of an increased fertilizer level (from 6 to

Table 1. Mean Se content of oat (mg kg^{-1}) in official variety trials, precipitation, effective temperature sum, soil pH and type at different trial locations during 1997–1999.

Location	Year	Precipitation May-Aug mm	Effective temperature sum	Soil pH	Soil type	Se content mg kg^{-1} dry weight Mean ± SD
Jokioinen	1997	302	1217	6.3	sandy clay	0.030 ± 0.007
	1998	318	1011	5.8	clay	0.070 ± 0.009
	1999	146	1184	5.7	sandy clay	0.180 ± 0.030
Mietoinen 1	1997	232	1285	5.3	clay	0.030 ± 0.004
	1998	245	1036	5.9	sandy clay	0.110 ± 0.009
	1999	92	1236	5.8	sandy clay	0.170 ± 0.030
Mietoinen 2	1999	92	1236	6.3	clay	0.100 ± 0.010
Tuusula	1997	n.a.	n.a.	6.3	sandy clay loam	0.170 ± 0.020
	1998	n.a.	n.a.	6.0	coarse silt	0.070 ± 0.010
Pälkäne	1997	253	1250	5.7	fine silt	0.095 ± 0.009
	1998	339	1043	6.0	fine silt	0.100 ± 0.008
	1999	141	1231	5.9	fine silt	0.240 ± 0.050
Mikkeli	1997	115	1150	6.9	fine sand	0.410 ± 0.040
	1998	337	976	6.0	fine sand	0.230 ± 0.030
	1999	243	1133	6.0	fine sand	0.200 ± 0.010
Maaninka	1997	177	1153	5.8	coarse silt	0.130 ± 0.020
	1998	340	938	6.1	coarse silt	0.050 ± 0.006
	1999	183	1134	5.5	coarse silt	0.240 ± 0.050
Laukaa	1997	182	1146	6.0	coarse silt	0.110 ± 0.010
	1998	345	916	6.0	coarse silt	0.090 ± 0.010
	1999	175	1112	6.0	coarse silt	0.180 ± 0.020
Ylistaro 1	1997	155	1143	6.0	sandy clay loam	0.060 ± 0.010
	1998	372	937	6.2	silty clay	0.060 ± 0.010
	1999	120	1062	6.1	silty clay	0.180 ± 0.040
Ylistaro 2	1997	155	1143	5.3	mould	0.020 ± 0.003
	1998	372	937	5.7	mould	0.040 ± 0.006
	1999	120	1062	5.5	mould	0.050 ± 0.008
Ruukki 1	1998	439	850	5.9	coarse silt	0.050 ± 0.003
	1999	182	952	5.4	coarse silt	0.050 ± 0.010
Ruukki 2	1999	182	952	5.4	mould	0.030 ± 0.004
Vihti	1998	389	997	5.9	coarse silt	0.120 ± 0.020
	1999	132	1173	6.2	clay	0.380 ± 0.080

n.a. not available
SD standard deviation

10 mg Se kg^{-1} fertiliser), but also the effect of very low precipitation in 1999. The cold and rainy growing season in 1997 probably decreased the Se contents of oats in some soil types due to increased leaching and reduction.

The effect of increased Se supplementation dosage in 1999 also clearly affected the oats during normal farming practices. The mean Se contents doubled in 1998–1999 from 0.050 to 0.130 mg kg^{-1}dw. The variation between farms was very large, < 0.010–0.110 mg kg^{-1} dw (n = 75) in 1998 and < 0.010–0.334 mg kg^{-1} dw (n = 88) in 1999. The Se concentrations during normal farming practices were generally slightly lower than in the research stations variety trials, where the fertilization levels and soil pH tended to be somewhat higher than those which generally occur in Finland. The farm samples were not hulled either. When the Se is mainly associated with the protein fraction of the grain it is more concentrated in the groats than in the grains. The mean Se contents of oats are currently very near the original Se supplementation target value for cereal grains, about 0.1 mg kg^{-1}.

The Se concentrations found were similar to those occurring in previous Finnish studies performed during the period of Se fertilization. The Se contents of oats in 1972–1976 were found to be very low, generally below < 0.010 mg kg^{-1} dw (Varo et al. 1980b). After initiation of Se fertilization in 1985–1992, the Se contents of oat grains varied between 0.004 and 0.840 mg kg^{-1} dw. The highest values occurred in 1988–1989 when the mean Se concentrations of oat grains were 0.260 and 0.230 mg kg^{-1} dw, respectively (Ministry of Agriculture and Forestry 1994, Ekholm 1997).

Organic vs. conventional cultivation

Comparison of organic and conventional cultivation of oats was tested in the same field with cultivars Veli and Puhti (Fig. 1). The mean Se content in organic cultivation was < 0.010 mg kg^{-1} dw and in conventional cultivation 0.040 mg kg^{-1}dw. The Se contents were distinctly lower during the rainy and cold growing season in 1998. The absence of Se fertilization was clearly seen. Organic cultivation resulted in significantly (P = 0.006, confidence interval –4.1 to –1.0) lower Se contents than conventional cultivation. The only exception occurred during the 1998 trial in Jokioinen where the Se contents were higher in organic cultivation for reasons that remain unclear. Some recent studies concerning organically grown foods have also shown very low Se contents in organically grown cereal and vegetable products (Eurola et al. 2000, Eurola and Ekholm 2002). This suggests that in organic animal production increased efforts are needed to ensure the sufficient Se content of feeds, especially when farm feeds are used.

Cultivar differences

Significant (P < 0.001) cultivar differences were detected in official variety trials. Cultivars Veli and Leila had higher and cultivars Salo, Roope and Belinda lower Se contents than the other cultivars studied (Table 2). The difference between the mean Se concentrations of cultivars was 24%. The Se content of Veli was also significantly (P = 0.002) higher in organic vs. conventional cultivation trials. The effect of cultivar on Se contents in organic cultivation variety trials could not be analysed, since over 80% of the Se concentrations were below the detection

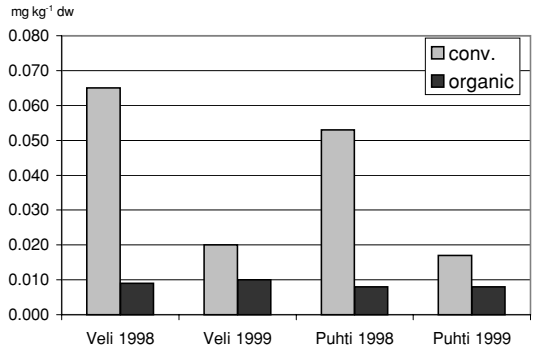

Fig. 1. Se contents (mg kg^{-1}) of oats in organic and conventional cultivation during 1997–1998.

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Table 2. Se content of oat cultivars (mg kg^{-1}) in official variety trials 1997–1999.

Cultivar	Year 1997	1998	1999	Number of trials	All original[a]	All Log(x)	Standard Error of means
n	52	55	56				
Range	0.016–0.460	0.030–0.270	0.016–0.460				
Veli	0.130	0.100	0.190	31	0.140a	4.67	0.132
Leila	0.130	0.100	0.170	22	0.130a	4.62	0.132
Kolbu	0.100	0.060	0.130	32	0.120b	4.52	0.133
Roope	0.100	0.070	0.160	32	0.120bc	4.51	0.133
Belinda	0.110	0.080	0.160	21	0.120bc	4.50	0.133
Salo	0.110	0.090	0.130	25	0.110c	4.42	0.132
Median	0.090	0.070	0.170	163	0.100		
Mean	0.110	0.090	0.160	163	0.110		

[a] Means followed by the same letter are not significantly different at $P < 0.05$
Statistical analyses are based on log-transformed (Log(x)) values.

limit. The Se levels were so low that any possible differences between the cultivars were insignificant.

In conclusion, the Se fertilization has significantly affected the Se content of cereals and other agricultural products in Finland. In the present study the mean Se contents of conventionally cultivated oats were at sufficient level and meat well the original Se supplementation target value for cereal grains, about 0.1 mg kg^{-1}. However the Se contents varied considerably on annual basis and between different locations due to the variations in fertilizing rates and different soil and climatic conditions. In organic cultivation the Se contents of oats were very low, which should be noted in organic animal production. In official variety trials the cultivar significantly affected the Se contents of oats indicating the also presence of genetic variations. These existing differences make it possible to cultivate or develop cultivars likely to accumulate more Se, if necessary.

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SELOSTUS

Suomalaisen kauran seleenipitoisuus vuosina 1997–1999

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Tutkimus oli osa Kaura raaka-aineen laadunohjausjärjestelmä -hanketta, jossa selvitettiin laajasti suomalaisen kauran laatua ja soveltuvuutta elintarvikeja rehukäyttöön. Tavoitteena oli selvittää kauran seleenipitoisuuksia sekä lajikkeen ja luomuviljelyn vaikutusta seleenipitoisuuksiin. Näyteaineisto koostui MTT:n tutkimusasemien ja yhteistyökumppanien kaurakokeiden satonäytteistä sekä seleeniseurantatutkimuksen yhteydessä Kasvintuotannon tarkastuskeskuksesta saaduista tilanäytteistä.

Virallisissa lajikekokeissa kauran keskimääräiset seleenipitoisuudet olivat 0,110, 0,120 and 0,160 mg kg^{-1} kuiva-ainetta vuosina 1997–1999 vaihteluvälin ollessa 0,016–0,460 mg kg^{-1} kuiva-ainetta. Tilanäytteiden keskimääräiset seleenipitoisuudet olivat 0,050 and 0,130 mg kg^{-1} kuiva-ainetta vuosina 1998–1999, vaihteluväli <0,010–0,330 mg kg^{-1}kuiva-ainetta.

Suomessa vuodesta 1984 alkanut seleenin lisääminen moniravinteisiin lannoitteisiin on tärkein viljojen seleenipitoisuuksiin vaikuttava tekijä. Vuonna 1998 seleenin määrää lannoitteissa nostettiin 6:sta 10 mg:aan kilossa, mikä näkyy myös tässä tutkimuksessa kauran suurempina seleenipitoisuuksina vuonna 1999. Myös maaperä ja ilmastolliset tekijät vaikuttavat liukoisen, kasveille käyttökelpoisen seleenin määrään maassa ja sitä kautta kauran seleenipitoisuuksien vaihteluun. Esimerkiksi satokausi 1998 oli hyvin sateinen ja viileä, jolloin seleenipitoisuudet jäivät monilla koepaikoilla pienemmiksi kuin muina tutkimusvuosina. Kauran keskimääräiset seleenipitoisuudet ovat nyt lähellä alkuperäistä seleenilannoitukselle asetettua tavoitetasoa, joka on viljoille 0,1 mg kg^{-1}.

Virallisissa lajikekokeissa eri lajikkeiden seleenipitoisuudet poikkesivat toisistaan selvästi. Veli- ja Leila-lajikkeiden seleenipitoisuudet olivat systemaattisesti suurempia kaikkina tutkimusvuosina. Luomulajikekokeissa lajikkeiden välisiä eroja ei voitu havaita, koska seleenipitoisuudet olivat alle määritysrajan, 0,010 mg kg^{-1}. Seleenilannoituksen puute näkyy selvästi luomuviljelyssä, jossa kauran seleenipitoisuudet olivat pienempiä kuin tavanomaisessa viljelyssä.