Yield, SDG lignan, cadmium, lead, oil and protein contents of linseed (*Linum usitatissimum* L.) cultivated in trials and at different farm conditions in the south-western part of Finland

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Linseed varieties were studied in variety trials and under farm conditions in south-western Finland in the years 2007−2010. The variation in yield, oil, protein, SDG lignan, cadmium and lead contents were studied in 8 oil and 2 fibre linseed varieties. Genotypic, environmental and genotype x environment interaction variance estimates were calculated. Fibre varieties ‘Belinka’ and ‘Martta’ had higher protein and lower oil contents than oil linseed varieties. The SDG lignan contents of linseed varieties varied between 3635−9560 mg kg^{-1}. Rather high genotypic variance was found in yield, oil, protein and SDG lignan contents. ‘Abacus’, ‘Helmi’ and ‘Martta’ had the highest SDG lignan contents while ‘Laser’ had a lower SDG lignan content. Variation in cadmium and lead contents was caused by environmental effects. The highest cadmium contents, 0.82−1.69 mg kg^{-1}, were found in soils fertilized by wastewater sludge about 20 years ago and at fields with low bottom soil pH (4.1−4.5).

Key words: soil pH, flax, wastewater sludge fertilization, genotypic variance

Introduction

Linseed (*Linum usitatissimum* L.) is an oil crop cultivated in small extent in Finland. Some 2000 ha of linseed are cultivated annually in the southern part of Finland but large amounts of linseed are also imported to Finland every year. Linseed contains nutritional oil with high linolenic acid content, good quality protein and especially high lignan content.

Linseed is one of the richest sources of lignans used in the human diet. The seeds of linseed and sesame (*Sesamum indicum*) contain high lignan contents compared to other food crops (Smeds et al. 2007). The major lignan in linseed is secoisolariciresinol, which is present as a diglucoside (SDG) linked to oligomers mainly by 3-hydroxy-3-methyl glutaryl esters (Ford et al. 2001, Kamal-Eldin et al. 2001). After ingestion lignans like SDG undergo transformations and finally form mammalian lignans, enterodiol and entero-lactone, through conversion by intestinal microbes. Through their antioxidant activity and ability to bind divalent metal cations, lignans are beneficial to human health. Various health effects have been linked to SDG lignan, including cardiovascular heart health, the control of diabetes, and the reduction of the risk of certain cancer types (breast, colon and lung) (Adolphe et al. 2010, Toure and Xueming 2010).

Cadmium and lead are harmful elements in the diet of humans. Chronic low-dose exposure, e.g. via food, to cadmium has various adverse health effects in human beings (Satarug et al. 2010). Cadmium and lead are especially harmful to children (Thatcher et al. 1982, Wright et al. 2006). Recently, cadmium has also been found to cause estrogen-like effects *in vitro* and *in vivo* (Johnson et al. 2003) thereby causing a higher risk of breast cancer in human beings (McElroy et al. 2006).

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High cadmium and lead contents in soil and plants are found near the sides of main roads (Lagerwerff and Specht 1970, Motto et al. 1970) and near metal and mine industry areas (Liu et al. 2005). High concentrations of cadmium are also found in fields fertilized by wastewater sludge (Davis 1984). Several phosphate fertilizers contain cadmium. The cadmium content of fields has increased by 10 fold under phosphate fertilization in several soils (Williams and David 1976). Different plants and different plant parts accumulate different amounts of cadmium (Matt 1970). The leaves and stems of crops are usually more contaminated by heavy metals than seeds and fruits (Liu et al. 2005). Linseed has a tendency, however, to accumulate cadmium from the soil to the seeds (Kymäläinen and Sjöberg 2006). Cadmium accumulation by plants depends on the amount and solubility of cadmium in soil, the soil pH and soil type, and on some other metal contents, e.g. Zn in soil (Grant et al. 1998, Zhao and Saigusa 2007). Cadmium solubility is increased by a low soil pH (Zhao and Saigusa 2007). Cadmium uptake to plants is competitive with Zn uptake from the soil (Grant et al. 1998).

In the present research several varieties of oil and fibre linseed were studied in variety trials, in farm variety trials and under different farm field conditions in south-western part of Finland over four-year period. Different oil and fibre linseed varieties were studied in relation to their performance in the conditions of south-western Finland, because only very limited official information exits on the performance of linseed varieties in Finland. The yields and chemical quality were studied for the beneficial SDG lignan, oil and protein contents, and the harmful, cadmium and lead contents in different varieties and in varying field cultivation conditions. Weather conditions during growing period, soil types, and pH of soils vary greatly in Finland. The main aim of the study was to discover the level of yield and nutritionally beneficial lignan and harmful cadmium and lead contents in different varieties and environments. Genetic and environmental variation and the stability of the characteristics in varying conditions were studied. The effects of variety, year and location on yield and chemical quality of linseed were calculated and discussed.

Materials and methods

Plant materials, trials, fields and weather conditions

Linseed seed samples were collected from farms in 2007−2010. These included samples from two linseed varieties, ‘Helmi’ and ‘Laser’. A replicated variety trial was established at the MTT Agrifood Research Finland station in Kaarina near Turku in south-western Finland in 2009 and 2010. The trial design comprised randomized blocks with 4 replications. The harvested plot size was 10.31 m^2. The weeds were suppressed by amidosulfuron (Gratil) 40 g ha^{-1} in both years. A replicated linseed variety trial was established also at a farm in Kylmäkoski near Tampere in 2010. The farm trial was established by direct seeding. The trial had 3 replications and the harvested plot size was 500 m^2. The weeds were suppressed by a mixture of amidosulfuron (Gratil) 20 g ha^{-1} and metsulfuron methyl (Ally 50 ST) 3 g ha^{-1}.

The oil linseed varieties in the trials were ‘Abacus’, ‘Aries’, ‘Comtess’, ‘Heljä’, ‘Helmi’, ‘Laser’, ‘Sunrise’, ‘Taurus’, and the fibre varieties ‘Belinka’ and ‘Martta’. Linseed crops at trials and farm fields were combine-harvested and dried after harvesting. The data for sowing and harvesting, fertilization, soil pH and nutrients at farms and trials are given in Table 1. The nutrient contents of the soils have been analysed by the acid ammonium acetate extraction method described by Vuorinen and Mäkitie (1955). Soil pH was measured after dissolving soil samples in distilled water. Cultivation data was not obtained from every farm. Seed samples were obtained without cultivation data from Loimaa (60° 51’ N longitude, 23° 03’ E latitude) and Kiukainen (61° 12’N longitude, 22° 05’ E latitude). Weather conditions at 4 places of the cultivation area in the cultivation years 2007−2010 are shown in Table 2. Precipitation was also measured at the farm trial at Kylmäkoski in 2010. 2010 was warmer than other years. In Pori the differences in growth temperatures between different years were not as great as in other locations, Kaarina, Jokioinen (60° 48’ N longitude, 23° 29’ E latitude) and Tampere, Pirkkala (61° 27’ N longitude, 23° 38’ E latitude).

Field 3 at Pori in 2008 had suffered wastewater sludge fertilization about 20 years ago (Table 1, Jukka Kaijanen, personal information). The sludge has had high Ca and Cd contents. The fields at Pori are near the sea coast and formed part of the sea bed. The cultivation of these fields began in the 1950s. The bottom soils in these fields are very acid so-called sulphate soils (Table 1).

Chemical analyses

Oil, protein, SDG lignan, cadmium and lead contents were analysed from the seed samples of trials and farm linseed samples. Protein contents were analysed only from the samples from 2008−10. Oil and protein contents were analysed in the samples at the laboratories of Viljavuuspalvelu Ltd. Protein contents were analysed by the Kjeldahl method using a FINAS (Finnish Accreditation Service) ISO/IEC 17025: 2005 accredited method. The oil contents were analysed by a national official method used for oil crops in Finland (MMM 1991). Oil was extracted by a heptane ethanol mixture (heptane 75 % : absolute ethanol 25 %) and measured quantitatively. SDG lignan contents were analysed from the crushed seeds after oil removal and alkaline hydrolysis by liquid chromatography using a diode array detector (Muir and Westcott 2000 with slight modifications). Cadmium and lead contents of the samples were analysed by ICP mass spectrometer after wet digestion by HNO_3. SDG lignan, cadmium and lead analyses were carried out at the MTT Laboratories.

Statistical calculations

The results were calculated using the Statistica programme. The effects of varieties, year and locations, and the differences between varieties, locations and years were tested using the ANOVA programme. Two models were used to test the variety-by-location interactions. First the interaction was tested using SAS/MIXED software by adding interaction effect to the original model as a fixed effect. Because only a few varieties were tested in more than one location, the magnitude of interaction was estimated using variance component model (=second model). All effects (variety, year, location, variety-by-location) were included as random effects in variance component model and variances were estimated using REML-estimation method.

Genotypic and environmental variance and genotype x environment interaction estimates were calculated from the variance components for the yield and chemical quality parameters of linseed according to the following equation (Falconer 1981):

$\delta_P^2 = \delta_g^2 + \delta_e^2 + \delta_{ge}^2$,

where

δ_P^2 = phenotypic variance

δ_g^2= genotypic variance

δ_e^2 = environmental variance

δ_{ge}^2 = genotype x environment interaction

Table 1. Data of linseed fields and trials and cultivation conditions

Location	Location		Year	Type of field	Date of sowing	Soil type	Data of soil pH and nutrients						Fertization, kg ha^{-1}			Date of harvesting	Yield kg ha^{-1} (mean)
	N longitude	E latutude					pH	Ca mg l^{-1}	P mg l^{-1}	K mg l^{-1}	Mg mg l^{-1}	pH of bottom soil	N	P	K		
Kuusjoki	60°31’	23°13’	2007	Farm	12 May	fine sandy clay	5,8	2323	5,9	356	1005		60,0	7,8	13,1	26 October	1600
Luopioinen	61°21’	24°39’	2007	Farm	28 April	silty clay	6,8	2720	22,0	283	352		29,0	7,0	22,0		
Pori, Field 1	61°29’	21°47’	2007	Farm	2 May	loam clay	6,4	1953	11,0	176	321	4,1	70,0	0,0	52,0	25 September	950
Pori, Field 2	61°29’	21°47’	2007	Farm	3 May	loam clay and silty clay	6,5	1915	10,4	210	274	4,5	60,0	0,0	45,0	19 September	1420
Ruovesi	61°59’	24°04’	2007	Farm	6 May	fine sandy silt	5,6	783	4,7	106	158		50,0	7,5	20,0	28 September	1200
Kylmäkoski	61°09’	23°41’	2007	Farm	14 May	fine sandy clay	6,5	2910	6,4	333	962		55,0	7,5	15,0	26 October	1500
Yläne	60°52’	22°24’	2007	Farm	10 May	fine sandy clay							48,3	3,0	7,0		
Pori, Field 3	61°29’	21°47’	2008	Farm			7,5	4300	55,0	120	130						
Kaarina	60°24’	22°22’	2009	Trial	14 May	fine sandy clay	6,5	2600	21,0	203	235		72,2	0	25,3	24 September	2250
Kaarina	60°24’	22°22’	2010	Trial	26 May	silty clay	6,0	3800	8,4	250	170		71,5	0	22,8	7 September	1650
Kylmäkoski	61°09’	23°41’	2010	Farm trial	14 May	loam clay	5,9	3550	3,5	165	440		47,4	13,7	4,7	29 September	2330

Table 2. Mean temperature and precipitation in May-September at 4 locations of south-western part of Finland in 2007–2010 compared to normal conditions (1971–2000) (Data is from Finnish Meteorological Institute, Finland, http:/www.fmi/saa/tilastot.html.).

Location	Year	Mean temperature °C	Precipitation mm	Mean temperature in 1971–2000 °C	Precipitation in 1971–2000 mm	Deviation from normal	
						Mean temperature °C	Precipitation mm
Jokioinen	2007	13,6	311	13,0	318	0,5	-7
	2008	12,6	288	13,0	318	-0,4	-30
	2009	13,6	246	13,0	318	0,5	-72
	2010	14,6	291	13,0	318	1,6	-27
Kaarina	2007	14,1	284	13,6	310	0,6	-25
	2008	13,3	272	13,6	310	-0,3	-38
	2009	13,8	255	13,6	310	0,3	-55
	2010	14,9	289	13,6	310	1,4	-20
Pori	2007	13,8	380	12,9	290	0,9	90
	2008	12,6	275	12,9	290	-0,2	-15
	2009	13,7	315	12,9	290	0,9	25
	2010	13,5	342	12,9	290	0,6	52
Tampere, Pirkkala	2007	13,5	364	12,9	306	0,6	58
	2008	12,2	314	12,9	306	-0,7	8
	2009	13,4	255	12,9	306	0,5	-51
	2010	14,6	332	12,9	306	1,7	26
Kylmäkoski	2010		294				

Results and discussion

Yield, oil, protein and SDG lignan contents of linseed

The chemical quality of linseed samples was good, having high levels of oil and protein (Table 3). The oil content of linseed varieties varied from 42.5 g 100 g^{-1} to 48.8 g 100 g^{-1} of dry matter (Table 3). The 'Helmi' variety had lower oil content than other oil linseed varieties (Table 4). The oil contents of fibre varieties 'Martta' (40.2 g 100 g^{-1}) and 'Belinka' (34.8 g 100 $g^{-1)}$) were lower than those of oil linseed varieties. The differences in oil and protein contents between oil and fibre linseed varieties were significant (Table 3). The fibre varieties, 'Martta' and 'Belinka', had higher protein contents (26.2 and 27.5 g 100 g^{-1}) compared to the oil linseed varieties (Table 4). In oil crops oil and protein are very often negatively correlated characteristics. The varieties differed in terms of oil contents (Table 4).

Differences caused by genotype, year, location and interactions between genotype x year and genotype x location could be calculated. The genotypic variance estimate was rather high for yield (28 %) and high for protein (47 %) and oil content (55 %) of linseed in this material (Table 5). There were, however, no significant differences in yield of varieties (Table 4). The yields of oil linseed varieties were higher than the seed yields of the fibre varieties. The genotype x year and genotype x location interactions for protein content was very low < 1 %. The genotype x year interaction for oil content was 16 % and genotype x location interaction was 4 % from the total variance.

Table 3. Oil, protein, SDG lignan, cadmium and lead contents in oil and fibre linseed varieties

Material	Chemical compound	Samples	Mean	Min	Max	SD[1]	F-test between variety groups			
		n					F value	*p* value	df factor	df error
Oil linseed varieties	Oil content, g 100 g^{-1}	32	45.0	40.0	50.3	2.7				
	Protein content, g 100 g^{-1}	21	22.7	18.5	28.3	2.5				
	SDG Lignan content, mg kg^{-1}	32	5706	3369	9070	1605				
	Cadmium content, mg kg^{-1}	32	0.538	0.250	1.690	0.282				
	Lead content, mg kg^{-1}	32	0.029	0.006	0.091	0.020				
Fibre linseed varieties	Oil content, g 100 g^{-1}	5	37.0	28.2	41.8	5.7	27.73	0.000	1	35
	Protein content, g 100 g^{-1}	5	26.7	24.8	30.2	2.2	10.84	0.000	1	24
	SDG Lignan content, mg kg^{-1}	5	6822	5342	9560	1938	1.98	0.003	1	35
	Cadmium content, mg kg^{-1}	5	0.538	0.420	0.630	0.102	0.00	0.997	1	35
	Lead content, mg kg^{-1}	5	0.012	0.007	0.024	0.007	3.41	0.073	1	35
All varieties	Oil content, g 100 g^{-1}	37	43.9	28.2	50.3	4.2				
	Protein content, g 100 g^{-1}	26	23.5	18.5	30.2	2.9				
	SDG Lignan content, mg kg^{-1}	37	5857	3369	9560	1669				
	Cadmium content, mg kg^{-1}	37	0.538	0.250	1.690	0.264				
	Lead content, mg kg^{-1}	37	0.027	0.006	0.091	0.020				

[1]SD= standard deviation

The environmental variances were 52 % for protein content and 24 % for oil content (Table 5). The variance caused by location was very small, < 1 %, for both characteristics. The environmental variance for oil content was caused by the effect of the year. The environmental effect for protein content was caused by year and the environmental effect for protein content was caused by year and location x year interaction. The highest protein contents were found in the year 2010, especially in Kaarina. The mean temperature of the year 2010 was higher than in other years (Table 2), which explained the higher protein contents of linseed. There was no great difference in precipitation in Kaarina between the years. High temperature and dryness increase the protein content of seeds in many crops (Dornbos and Mullen 1992, Wrigley et al. 1994). Tadesse et al. (2010) have found an estimate of heritability (=genotypic variance) of 59 % for oil content in linseed and of 78 % for yield in 81 genotypes under Ethiopian conditions. Genotypic variance is the heritability estimate in broad sense which reveals how good a character is inherited. The heritability estimate of oil content of Tadesse et al. (2010) is fairly near the estimate of present study despite the limited size of our material.

Significant differences between varieties were found in SDG lignan contents (Table 3 and 4). SDG lignan contents were higher in 'Abacus', 'Helmi' and 'Martta' compared to other varieties (Table 3). The highest SDG lignan content was found in the 'Martta' variety (7559 mg kg^{-1}). An especially low SDG lignan content was found in the 'Laser', 'Aries' and 'Comtess' linseed varieties. Diederichsen and Fu (2008) have reported a mean value of 11 340 +/- 3 850 mg kg^{-1} (3 600–19 000 mg kg^{-1}) lignan content in flax germplasm collection. Thompson et al. (1997) have tested 10 linseed varieties and found significant differences in the lignan content of varieties. Eliasson et al. (2003) have found differences in the SDG lignan content of linseed varieties in Sweden (4 660–15 440 mg kg^{-1}), the highest lignan contents being found in 'Jupiter' and 'Barbara' varieties (15 440 and 15 075 mg kg^{-1} in whole seed). Zimmermann et al. (2006) have tested linseed varieties in Germany and Spain and found that the variety markedly effects on the SDG lignan content.

Table 4. Yield, oil, protein, SDG lignan, cadmium and lead contents of varieties cultivated in 2007-2010

Type of variety	Variety	Number of samples	Yield kg ha^{-1}	Number of samples	Oil content g 100 g^{-1}		Protein content g 100 g^{-1}		SDG Lignan content mg kg^{-1}		Cadmium content mg kg^{-1}		Lead content mg kg^{-1}	
		n	mean*	n	mean	SD[1]	mean	SD[1]	mean	SD[1]	mean	SD[1]	mean	SD[1]
Oil	Helmi	3	1986	9	42.5	1.48	25.0	3.04	7229	1205	0.797	0.42	0.031	0.02
	Heljä	3	2079	3	45.8	3.23	24.1	3.27	6477	2173	0.523	0.08	0.012	0.01
	Laser	4	2305	13	45.8	2.39	20.8	2.35	4497	705	0.414	0.11	0.039	0.02
	Taurus	2	2455	2	45.0	0.23	23.8	2.55	5529	270	0.400	0.00	0.013	0.00
	Sunsrise	1	2654	2	48.0	3.24	21.2	0.57	6432	1779	0.460	0.11	0.015	0.00
	Abacus	1	2455	1	48.8		19.4		7120		0.460		0.010	
	Aries	1	2190	1	44.8		25.2		3635		0.390		0.021	
	Comtess	1	2451	1	44.8		22.4		3635		0.390		0.021	
Fibre	Martta	2	1636	2	40.2	1.69	27.5	3.82	7559	2830	0.600	0.04	0.016	0.01
	Belinka	3	1396	3	34.8	6.79	26.2	1.06	6330	1612	0.497	0.12	0.010	0.00
F-test between varieties														
F-value			2.04		2.42		5.81		3.92		1.66		1.48	
p-value			2.035		0.0594		0.00017		0.0028		0.1492		0.2045	
df variety			9		9		9		9		9		9	
df error			12		16		27		27		27		27	

*=in variety trials
[1]SD= standard deviation

Table 5. Variance estimates, %, for genotypic, environmental and genotype x environment interaction for yield, oil, protein, SDG lignan, cadmium and lead contents

Variance sourse		Yield	Oil content	Protein content	SDG Lignan content	Cadmium content	Lead content
Genotype		28	55	47	42	<1	<1
Environment	Location	<1	<1	<1	<1	55	59
	Year	54	24	14	7	3	31
	Location x Year	17	<1	39	51	41	10
	Total	71	24	52	58	99	100
Genotype x environment							
	Genotype x Year	<1	16	<1	<1	<1	<1
	Genotype x Location	<1	4	<1	<1	<1	<1
	Total	<1	20	<1	<1	<1	<1
Variance total		100	100	100	100	100	100

A rather high genotypic variance estimate, 42 %, was found in terms of the SDG lignan content in the present material (Table 5). Environmental variance was composed from the effect of year (7 %) and year x location interaction (51 %). Genotype x environment interaction was low, < 1 %. Thompson et al. (1997) have found a significant effect of the year on the lignan content of the '+Linott' variety. It seems that the SDG lignan content is influenced both by variety and environmental effects. The variety-by-location interaction was not significant, however (p=0.94). Thompson et al. (1997) have found a significant effect of the location on the lignan content of three studied varieties. Zimmermann et al. (2006) have found that the effect of the variety on the SDG lignan content of linseed is greater than the effect of either the location or the N-fertilization. In order to obtain good quality linseed for human consumption it is important to choose the right high SDG lignan cultivars for cultivation.

Harmful compounds: cadmium and lead contents

Linseed absorbed rather a lot of cadmium from the soil, the cadmium content of the seed varying from 0.25 to 1.69 mg kg^{-1} (Table 3). The differences in cadmium content between varieties were not high and no significant differences between varieties were found (Table 3 and 4). The genotypic variance estimate was very low, < 1 % (Table 5).). Kymäläinen and Sjöberg (2006) have reported differences in cadmium contents between 'Helmi', 'Heljä' and 'Laser' linseed varieties in Finland. Li et al. (1997) have found wide variation in cadmium contents (0.14−1.37 mg kg^{-1}) in 74 linseed lines. Hocking and McLaughlin (2000) have found differences in cadmium contents (0.233−0.545 mg kg^{-1}) between linseed genotypes in Australia. It has been discovered that the cadmium containing components are a few seed proteins (7 % of proteins) present in linseed (Lei et al. 2003). Low-cadmium selection programs have been developed for different crops (Grant et al. 2008). In durum wheat (*Triticum turgidum* L. *var. durum*) one dominant gene allele is responsible for a low cadmium content (Grant et al. 2008).

TheeEnvironmental variance component estimate was very high, 99 % for cadmium content due mainly to location (55 %) and location x year interaction (41 %) (Table 5). Especially high cadmium contents were present in the farm samples from Pori, on the western coast of Finland (Table 1 and 3-4, Figure 1). Cadmium contents of 4 samples from Pori varied 0.82−1.69 mg kg^{-1}. Pori is a major metal industry centre in Finland. The higher general level of cadmium in samples of Pori was possibly caused in part by the pollution from this industry. Kymäläinen and Sjöberg (2006) have reported, however, almost equally as high cadmium contents, 1.3 mg kg^{-1} in linseed from Siuntio, in Finlands' Uusimaa province. They have also found differences in cadmium contents of linseed between different years.

The highest cadmium contents (mean 1.24 and 1.69 mg kg^{-1}) were found in the 2008 samples from Pori. The field was fertilized by wastewater sludge about 20 years ago (Jukka Kaijanen, personal information). The 2007 cadmium contents from Pori (mean 0.83 mg kg^{-1}) were also higher than those from other locations. The fields in Pori are old sea bed with a very low pH in the bottom soil (Table 1). The main factor relating to cadmium solubility in soil is the pH. Cadmium solubility is increased by a low soil pH (Zhao and Saigusa 2007). Grant et al. (2000) found higher cadmium contents in years with higher precipitation. In Pori there was higher precipitation in 2007 than in 2008 (Table 2). The effect of precipitation was much smaller than the effect of soil type, in this case characterised by sludge fertilization. Especially high concentrations of cadmium are concentrated in fields fertilised by wastewater sludge (Davis 1984). Cadmium concentration is also very slowly reduced in soils fertilised by wastewater sludge. It has been found that less than 30 % of the cadmium from wastewater sludge has disappeared from the topsoil 15 years after sludge fertilisation (McBride et al. 1997). Mäkelä-Kurtto and Sippola (2002) have reported low cadmium contents, averaging 0.073 mg l^{-1}, from 705 field soil samples in Finland.

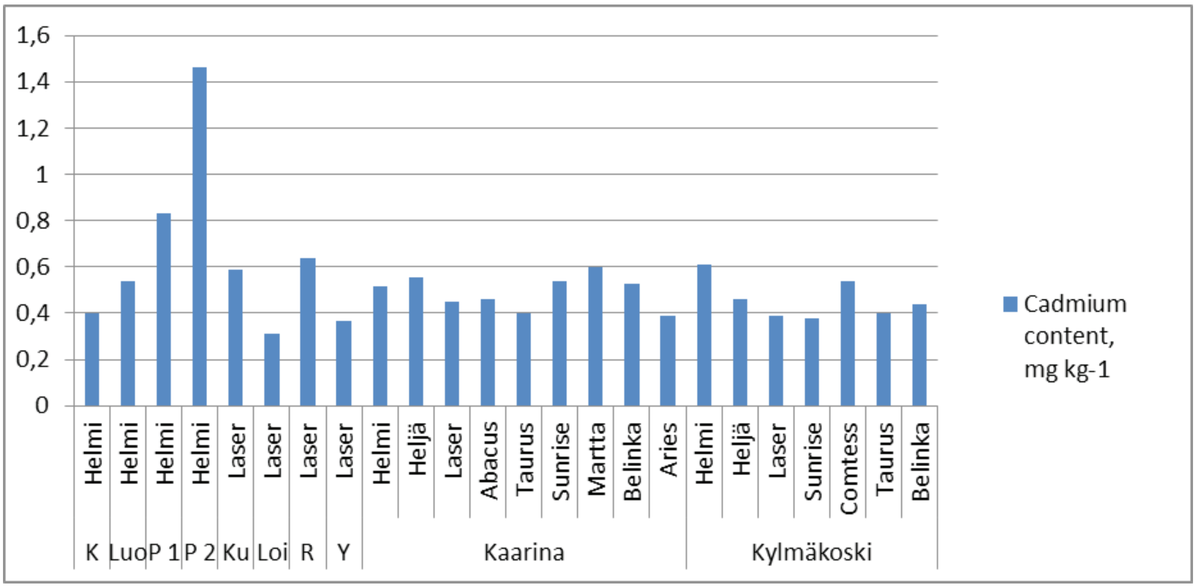

Fig. 1. Mean cadmium contents, mg kg^{-1}, in different varieties at different locations. K=Kiukainen, Luo=Luopioinen, P1=Pori 2007, P2= Pori 2008, Ku=Kuusjoki, Loi=Loimaa, R=Ruovesi, Y=Yläne.

The fields in Pori were situated near the sea coast about a kilometre from the delta of the River Kokemäenjoki and some kilometres from the sea and constituted the sea bed some 100 years ago. The cultivation of the present fields began in the 1950s. On the coasts of Finland there are so-called acid sulphate soils with high aluminium contents and a low pH. The pH of the fields in Pori was 7.5, 6.4 and 6.5, which does not explain the high cadmium contents of these Pori samples. The bottom soils of these fields have a very low pH (Table 1), however. Due to the proximity of the sea the water level in the soils is about 50 cm deep and the water may transport cadmium from deeper soil levels to plants, which possibly explains the high levels of cadmium in the Pori fields. The roots of linseed may reach the depth of 60 cm (Arny and Johnson 1928). A high cadmium content in linseed in Finland has also been reported earlier (Kymäläinen and Sjöberg 2006). Hocking and McLaughlin (2000) have found rather large differences in the cadmium contents of linseed between locations in Australia. The higher cadmium contents were caused by the use of phosphorus fertilizers containing cadmium. The present phosphorus fertilizers of Finland from the Siilinjärvi mine have a very low cadmium content. The cadmium content of phosphorus fertilizers from Siilinjärvi (Yara Ltd.) amounts to 12 mg Cd per 1 kg P. Previously, P fertilizers containing more cadmium were in use. According to the present results the location and cultivation history of a field were more important factors affecting the cadmium content of linseed rather than the variety.

Based on EY N:o 1881/2006 and EY N:o 629/2008, the maximum residue limit (MRL) in the EU for cadmium in cereals and legumes is 0.10 mg kg^{-1}, and for rice, wheat, bran and embryos 0.20 mg kg^{-1} (Evira 2009). There are no cadmium limits for linseeds in Finland. Evira, the Finnish Food Safety Authority, has, however, advised using linseed as food only occasionally and at a maximum of 2 spoonsfuls per day, while bread may not contain more than 10 % of linseed.

The lead contents were rather low in all samples (Table 3 and 4). No significant differences were found between varieties (Table 2 and 3). The genotypic variance estimate was low, < 1 % (Table 5). The environmental variance estimate composed by location (59 %), year (31 %) and location x year interaction (10 %). Lead contents from the Pori material were not higher than those from other locations. The highest lead contents are found in the vicinity of large roads (Lagerwerff and Specht 1970, Motto et al. 1970), and in mine and metal industry areas (Liu et al.

2005). In the present material no genetic variation in cadmium or lead contents was found.

Based on the results of this study, it can be concluded that high soil pH and avoiding wastewater sludge fertilization would partly prevent high cadmium levels of linseed.

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