Research Article

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Nutritive quality and protein production from grain legumes in a boreal climate

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Abstract

BACKGROUND: Boreal cropping systems are heavily focused on the production of small-grain cereals; to improve their resilience to climate change and to achieve food and feed security, diversification is needed. This study investigated the potential of faba bean, narrow-leafed lupin and lentil as protein crops in southern Finland, where faba bean is traditional but the other two are novel.

RESULTS: Early cultivars of narrow-leafed lupin and lentil matured adequately. Protein concentration in faba bean was, at 32%, higher than the world average of 29%, while those of narrow-leafed lupin and lentil were close to their world averages. Protein yields decreased in the order faba bean > narrow-leafed lupin > lentil. Lipid content of faba bean and lentil was about 1.2% and that of narrow-leafed lupin about 5.5%, and fatty acid composition was largely oleic and linoleic in all three species.

CONCLUSION: Both lentil and narrow-leafed lupin can be added to the range of feed and food crops produced at high latitudes in Europe. While faba bean produces the greatest protein yield and lysine concentration, the higher sulfur amino acid concentration in lupin, its oil content and its adaptation to acid, sandy soils not suitable for faba bean make it an attractive alternative.

Keywords: faba bean; narrow-leafed lupin; lentil; protein; fatty acids; seed composition

INTRODUCTION

The boreal region, with its characteristically long, cold winters and short growing season of about 3 months,[1] is a challenging environment for agricultural production, and as agricultural land area is restricted, so is the diversity of crops that are cultivated. The boreal climatic region is bounded with a July isotherm of 13 °C on the north and 18 °C on the south.[2] At the southern edge of the boreal zone, the cold season lasts more than 6 months, and the period with temperatures above 10 °C is up to 120 days.[3,4] The extremes of air temperature may reach −70 and +30 °C[5] and of latitude from 50 to 70° N.[6,7] All of mainland Finland is considered to lie within the thermal limits of the boreal zone, with a yearly average temperature of +4 to −1 °C.[8]

Boreal cropping systems are focused on the production of small-grain cereals, and the few other crops include rapeseed (oilseed rape, *Brassica napus* L., and turnip rape, *Brassica rapa* L.), potato (*Solanum tuberosum* L.) and sugar beet (*Beta vulgaris* L.), while grain legume crops are relatively neglected,[9,10] even by European standards. Pea (*Pisum sativum* L.) is the main grain legume in the boreal and nemoral regions of Europe, with less than 3000 ha in each of Denmark, Finland and Norway and about 8400 ha in Sweden.[11] Faba bean (*Vicia faba* L.) areas have risen in Finland and stabilized at 10 000 ha since 2010.[10]

Grain legume cultivation in the EU as a whole accounts for only 1.8% of arable land,[11] leading to overdependence on protein crop imports. Currently the EU imports 70% of its protein crop commodities to comply with the needs for feed of pigs and poultry.[12] In Finland, for example, soya bean (*Glycine max* (L.) Merr.) and rapeseed meal imports have risen steadily since 1961,[9] with peak imports of soya cake in 2010, while the imports of soya bean and oil have decreased considerably since 2005 (Fig. 1).[13]

In contrast, grain legumes are widely grown in the nemoral and boreal climates of the northern Great Plains of the USA and the prairies of Canada. They occupy 8% of Canadian arable land,[12] producing common bean (*Phaseolus vulgaris* L.), soya bean, chickpea (*Cicer arietinum* L.), pea and lentil (*Lens culinaris* Medik.), of which Canada is the top world producer.[11] Increased grain legume cultivation in the Canadian prairies is the result of extensive research to match the maturity requirements of crops with the climatic attributes and variability.[14–16] This suggests that it should be possible to grow grain legumes far more widely in the Nordic and Baltic regions of Europe.

Local cultivation of protein crops would not only reduce the dependence on imported soya bean products and inorganic fertilizers but also improve the sustainability of boreal cropping

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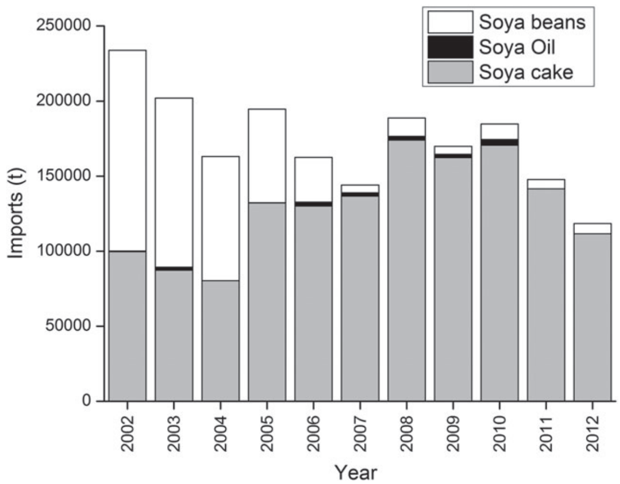

Figure 1. Imports of soya beans, cake and oil to Finland during 2002–2012.

systems and potentially contribute to better balanced human diets. Locally grown grain legume crops can help to reduce greenhouse gas (GHG) emissions associated with fertilizer use, livestock production and land use change outside the EU.[12] Grain legumes are essential components in the design of sustainable cropping systems owing to their well-known ecosystem services such as biological nitrogen fixation, increase of soil fertility and disruption of cereal disease cycles,[17] and thus help to provide resilience to climate change and to achieve local food and feed security.

The Finnish dependency on imported soya bean could be reduced by increasing the cultivation of protein crops, with some authors favoring the regionally traditional field pea and turnip rape, in spite of the low yield and high fertilizer requirements of the latter,[18] and others favoring higher-protein legumes such as faba bean and agricultural lupins.[9]

Hence we set out to explore the possibility to produce plant protein for food and feed uses from a range of grain legume species, focusing on cultivars that might be adapted to short growing seasons. We investigated faba bean, narrow-leafed lupin (*Lupinus angustifolius* L.) and lentil for their quality and protein production in the boreal climate of southern Finland.

MATERIALS AND METHODS

Field experiment and plant materials

Cultivars of faba bean, lentil and narrow-leafed lupin were screened during 2009–2012 at the Viikki Experimental Farm, University of Helsinki, Finland (60.224° N, 25.021° E). Helsinki is at the southern edge of the boreal zone, with a growing season of less than 120 days and a July isotherm of 17 °C. In all years the experiments were laid out as randomized complete block field trials with four replicates. Sowing dates were 7 May 2009, 15 May 2010, 10 May 2011 and 16 May 2012.

In each year the range of cultivars from different geographic origins differed, as they were also being inspected for earliness (Table 1). Plot sizes differed between years, being 2.5 m × 6 m in 2009, 1.25 m × 6 m in 2010 and 1.25 m × 8 m in 2011 and 2012. Row spacing was 25 cm in 2009 and 12.5 cm thereafter. Appropriate rhizobium inoculants were obtained from Elomestari Oy (Tornio, Finland) and applied to the seeds before planting. Plots were fertilized with 125 kg ha^{-1} of Cemagro 16-7-13 to provide 20 kg ha^{-1} of starter N. In 2009 and 2010 the soil was a silty clay loam of approximate composition 30–40% silt, 50–60% clay and 10–20% sand, with 6–12% organic matter content, conforming to the descriptions of Luvic Gleysols or Luvic Stagnosols.[19]

In 2011 and 2012 the experiments were done in a sandy clay soil classified as Endogleyic, Umbric Stagnosol (Dystric, Clayic). The organic C concentration in the topsoil was 6–10%. The soil had 33–49% clay in the plough layer and 54–68% clay in the subsoil (30–40 cm), where the pH ($CaCl_2$) was 3.8–4.8, and in the plough layer the pH had been raised by liming to 5.0.

Weather conditions

The 2009 growing season was wet and mild, 2010 was extremely dry with unusually high temperatures and drought during both July and August, 2011 was warm in the beginning but very wet in the end, and 2012 was remarkably wet, reaching a record precipitation of 480 mm (Table 2 and Fig. 2). The climate of the experimental field site clearly falls within the definition of 'boreal'.[4]

In order to compare weather conditions across years and to assess their influence on quality, the Sielianinow hydrothermal coefficient (K) was calculated by dividing the sum of monthly precipitation by one-tenth of the monthly average temperature. A value of K between 1.3 and 1.6 is optimal, while less than 1.3 is considered dry and greater than 1.6 humid.[20] Since the monthly index is rather crude, it was calculated as a 30 day running value from daily data (Fig. 1).

Phenology

Plant growth was monitored daily and dates were recorded when 10 and 90% of the plants in a plot reached flowering, finished flowering and reached harvest maturity. Growing degree days (GDD) to these points were calculated using a 5 °C base temperature. Results are shown for the four faba bean cultivars used in all years.

Measurements

At maturity, a subplot of 1 m^2 was harvested by hand from each plot, threshed, oven dried at 40 °C and the weight of 100 seeds was determined. The rest of the plot was machine harvested. Seed samples from the subplots were milled to pass a 0.5 mm sieve using a Centrifugal Mill ZM200 (Retsch, Haan, Germany). Nitrogen concentration was determined by the Dumas combustion method in a Vario Max CN analyzer (Elementar, Hanau, Germany) and multiplied by 6.25 to convert it to protein concentration.

In cultivars that matured with acceptable earliness, other quality factors were determined. Starch and fiber concentrations were determined using Megazyme total starch (K-TSTA 1107) and total fiber (K-TDFR 1205) kits (Megazyme, Bray, Ireland) (total fiber was measured on both faba bean and lentil, while soluble and insoluble fractions were measured on narrow-leafed lupin). Soluble sugar concentration was determined by the anthrone reagent method.[21] Oil concentration was analyzed using petroleum ether as solvent in a Soxtec™ 2055 system (AOAC 2003.06). Moisture and ash concentrations were determined by drying samples in an oven overnight at 105 °C and incinerating them in a muffle furnace at 600 °C. Amino acid analysis followed the standard procedure from Commission Directive 98/64/EC[22] with quantification by a UPLC Amino Acid Analysis Solution System (Waters, Milford, MA, USA). For fatty acid analysis, lipids were extracted using acetone as solvent by accelerated solvent extraction,[23] methylated and analyzed by gas chromatography (GC) using standard methods.[24]

Table 1. List of cultivars and number of years screened in the field

Species	Cultivar	Source	Years screened
Faba bean	Alexia	Gleisdorf	2010, 2011, 2012
	Aurora	Svalöf Weibull	2009, 2010, 2011
	Babylon	Nickerson Limagrain	2011, 2012
	Ben	Nickerson Limagrain	2010
	Columbo	DLF Trifolium	2010
	Disco	INRA	2010
	Divine	INRA	2011, 2012
	Espresso	NPZ	2010
	Fatima	Univ. Saskatchewan	2010, 2011, 2012
	Fuego	NPZ	2010
	GLA1103	Gleisdorf	2011
	Gracia	Gleisdorf	2010
	Jogeva	Jogeva PBI	2009
	Kontu	Boreal	2009, 2010, 2011, 2012
	Mélodie	INRA	2009, 2010, 2011
	Pyramid	Nickerson Limagrain	2010
	SSNS-1	Univ. Saskatchewan	2010, 2011, 2012
	Taifun	NPZ	2011
	Tangenta	NPZ	2010, 2011
	Tattoo	NPZ	2010
	Witkiem Manita	Tozer Seeds	2011
Lentil	Black	Univ. Göttingen	2010
	Blaze	Univ. Saskatchewan	2010
	Meteor	Univ. Saskatchewan	2010, 2011
	Milestone	Univ. Saskatchewan	2010, 2011, 2012
	Plato	Univ. Saskatchewan	2009
	Redberry	Univ. Saskatchewan	2009, 2010, 2011, 2012
	Redbow	Univ. Saskatchewan	2010, 2011, 2012
	Redcoat	Univ. Saskatchewan	2010
	Robin	Univ. Saskatchewan	2009, 2010
	Rosebud	Univ. Saskatchewan	2010, 2011, 2012
	Rosetown	Univ. Saskatchewan	2010, 2011
	Sedley	Univ. Saskatchewan	2009
	Sovereign	Univ. Saskatchewan	2010
	Viceroy	Univ. Saskatchewan	2009, 2010
Narrow-leafed lupin	Boregine	Saatzucht Steinach	2009
	Boruta	Saatzucht Steinach	2009, 2010, 2011
	Haags blaue	Saatzucht Steinach	2009, 2010, 2011, 2012
	Sanabor	Saatzucht Steinach	2009
	Sonet	Poznan Plant Breeders	2010, 2011

Since mechanical dehulling did not result in clean fractions of cotyledons and seed coats, a volumetric approach was used for the determination of seed coat content. Seed dimensions of 100 seeds of cultivars Kontu, Aurora and Mélodie harvested in 2009, 2010 and 2011 were measured with a precision micrometer, and seed volume was estimated from the standard mathematical equation for a smooth ellipsoid (volume $= \pi \times r_1 \times r_2 \times r_3 \times 4/3$). Seed coat fragments were chipped from seeds of all samples and their thickness was measured with the micrometer. The volume of dehulled seed was calculated by subtracting the seed coat thickness from each radius, and the volume proportion of seed coat was determined by subtracting the dehulled volume from the intact volume.

Statistical analysis

Results from all nutritive quality parameters were subjected to one- and two-way analysis of variance and correlation analysis using SPSS Version 21 (IBM, Armonk, NY, USA).

RESULTS

Some cultivars of all three species matured in a timely fashion in each year. Throughout the growing seasons of 2010 and 2011, the

Table 2. Monthly mean air temperature and total precipitation during the four growing seasons and long-term temperature (LTT) and precipitation (LTP) figures for the period 1971–2000 in Helsinki

Month	Air temperature (°C) 2009	2010	2011	2012	LTT (°C) (30 years)	Precipitation (mm) 2009	2010	2011	2012	LTP (mm) (30 years)
May	10.9	11.3	9.9	10.8	9.9	48	70	30	66	32
June	13.8	14.3	16.4	13.0	14.8	66	28	52	94	49
July	16.6	21.4	20.1	17.0	17.2	125	33	71	78	62
August	15.9	17.4	16.6	15.1	15.8	45	115	175	56	78
September	12.7	11.5	12.6	11.2	10.9	38	60	101	185	66
Mean	14.0	15.2	15.1	13.4						
Growing season record min.	0.8	0.4	0.0	2.3						
Growing season record max.	27.9	31.0	29.8	26.5						
Total						322	306	430	480	

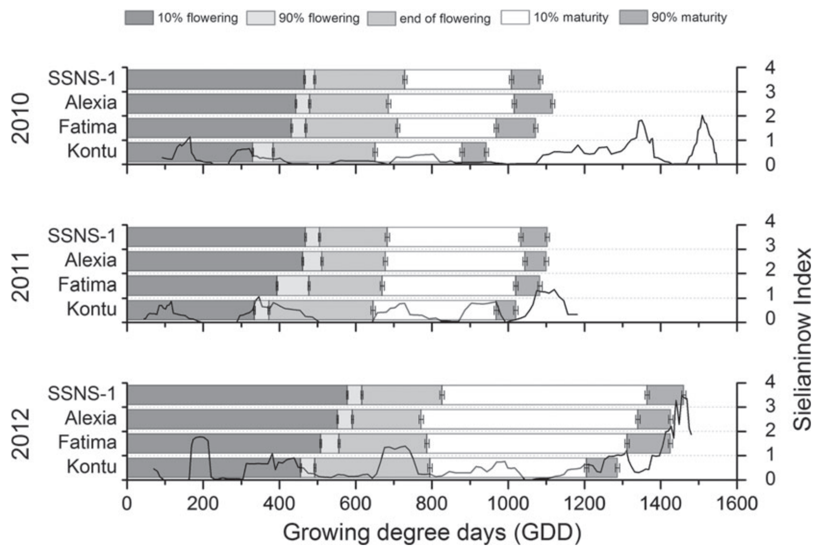

Figure 2. Phenological stages from sowing until maturity of four faba bean cultivars during 2010–2012. Phenological stages are expressed as growing degree days (GDD). The solid line shows the Sielianinow hydrothermal index (*K*) calculated as a 30 day running value from daily data.

Sielianinow index was well below the optimal range of 1.3–1.6 (Fig. 2). The contrast in weather between 2010 (dry) and 2012 (cool and wet) was associated with a major difference in GDD to maturity (as shown in Fig. 2 for faba bean) and some associated changes in nutritive quality.

Cultivars 'Haags Blaue' and 'Sonet' of narrow-leafed lupin and several cultivars of lentil consistently matured several days before the Finnish faba bean cultivar 'Kontu', except in 2010 when the severe summer drought killed most of the plants of 'Kontu' before they could senesce normally.

Protein yield and nutritive quality

Seed size, yield and protein yield were lowest in lentil, intermediate in narrow-leafed lupin and highest in faba bean (Table 3). Mean protein concentration was marginally higher in narrow-leafed lupin than in faba bean and lentil (Table 4). Dietary fiber concentration followed the same sequence. Starch concentration was higher in lentil than in faba bean and was virtually zero in narrow-leafed lupin, as expected. Oil and soluble sugar concentrations were higher in narrow-leafed lupin than in the other two species, and ash content was similar in all three.

There was significant intraspecific variation in protein concentration ($P < 0.001$) in each species, and there was also a significant interaction between cultivar and year in faba bean ($P < 0.001$, Fig. 3) and lentil ($P < 0.05$, Fig. 4) but not in narrow-leafed lupin ($P > 0.05$, Fig. 5). Furthermore, protein yield was also significantly different among cultivars of faba bean ($P < 0.001$) and narrow-leafed lupin ($P < 0.001$) but not in lentil ($P > 0.05$). As was the case for protein concentration, in protein yield the interaction of cultivar and year was significant in lentil ($P < 0.01$) and faba bean ($P < 0.01$) but not in narrow-leafed lupin ($P > 0.05$).

Seed size varied significantly across years and cultivars ($P < 0.001$) in each species, and there was a significant year × cultivar interaction in both faba bean ($P < 0.001$) and narrow-leafed lupin ($P < 0.01$) but not in lentil ($P > 0.05$).

Lentil cultivars showed little variation in other aspects of composition, except for total dietary fiber ($P < 0.05$). Fat and ash contents varied significantly among cultivars of both narrow-leafed lupin and faba bean, and in both species the year × cultivar interaction was also significant for both these traits ($P < 0.01$) (Figs 3–5 and Table 4).

Table 3. Seed size, yield and protein yield for faba bean, lentil and narrow-leafed lupin grown in Helsinki during 2009–2012

	Seed size (mg)			Yield (t ha^{-1})			Protein yield (t ha^{-1})		
Crop	Mean	SD	Number of data points	Mean	SD	Number of data points	Mean	SD	Number of data points
Faba bean	534	191	37	4.9	0.9	37	1.6	0.3	35
Lentil	42	10	22	1.4	0.4	22	0.4	0.1	18
Narrow-leafed lupin	151	24	11	3.1	1.0	11	1.1	0.4	10

SD, standard deviation.

Table 4. Chemical composition and amino acid profile for faba bean, lentil and narrow-leafed lupin grown in Helsinki during 2009–2012

	Faba bean			Lentil			Narrow-leafed lupin		
Parameter	Mean	SD	Number of data points[a]	Mean	SD	Number of data points[a]	Mean	SD	Number of data points[a]
Chemical composition (g kg^{-1})									
Protein (N × 6.25)	323.4	22.0	35	292.8	17.8	18	330.2	33.2	10
Starch	392.3	27.2	11	436.9	19.5	5	6.6	0.3	4
Fiber[b]	244.9	56.9	6	176.9	12.4	8	429.9	25.7	4
Fat	10.1	1.2	10	NM	NM	NM	67.6	6.3	7
Soluble sugars	27.8	5.5	11	26.3	3.1	5	56.5	9.5	7
Ash	35.8	3.7	35	38.1	40.9	18	37.5	2.1	10
Amino acids (g kg^{-1} dry matter)									
Alanine	12.1	0.3	10	11.0	0.6	6	10.5	0.7	3
Arginine	30.6	2.6	10	21.9	1.5	6	30.5	3.7	3
Aspargine	31.5	1.4	10	29.9	1.8	6	28.9	2.6	3
Cysteine	2.6	1.2	10	2.3	0.5	6	4.0	1.2	3
Glutamic acid	49.3	2.1	10	42.1	2.9	6	61.6	5.2	3
Glycine	12.7	0.5	10	10.7	0.6	6	12.9	1.1	3
Histidine	7.7	0.5	10	6.9	0.5	6	8.4	1.1	3
Isoleucine	11.5	0.5	10	10.6	0.8	6	11.4	1.1	3
Leucine	21.8	0.9	10	19.2	1.2	6	20.6	1.6	3
Lysine	18.5	0.5	10	17.8	1.1	6	14.3	0.9	3
Methionine	2.2	0.1	10	2.2	0.1	6	2.4	0.1	3
Phenylalanine	12.5	0.5	10	13.1	0.7	6	11.6	1.0	3
Proline	12.4	0.6	10	10.8	0.4	6	11.7	1.0	3
Serine	15.0	0.8	10	13.9	0.8	6	15.3	1.1	3
Threonine	10.6	0.4	10	9.9	0.5	6	10.9	0.8	3
Tryptophan	2.7	0.3	10	2.4	0.3	6	3.1	0.2	3
Tyrosine	9.7	0.5	10	8.0	0.6	6	10.3	1.0	3
Valine	12.7	0.5	10	11.8	1.0	6	11.1	1.1	3

SD, standard deviation; NM, not measured.
[a] Refers to cultivar × year means (see Table 1 for cultivar distribution across years).
[b] Refers to total dietary fiber in the case of faba bean and lentil but to insoluble + soluble fiber fractions in the case of narrow-leafed lupin; this addition was done to facilitate comparison between species.

Amino acid composition

There were significant differences between species for all essential amino acids, except in serine, asparagine, isoleucine, cysteine and methionine, the last two being the most limiting in grain legumes. Cysteine concentration was approximately 50% higher in narrow-leafed lupin than in faba bean and lentil, which had nearly the same amount, and methionine concentration was 10% higher in narrow-leafed lupin than in the other two species (Table 4). Tryptophan concentration was higher in narrow-leafed lupin than in the other two species ($P < 0.05$), and lysine concentration was lower ($P < 0.001$).

For nine amino acids, narrow-leafed lupin had the highest content, while faba bean had the highest in eight others and lentil was the highest only in phenylalanine.

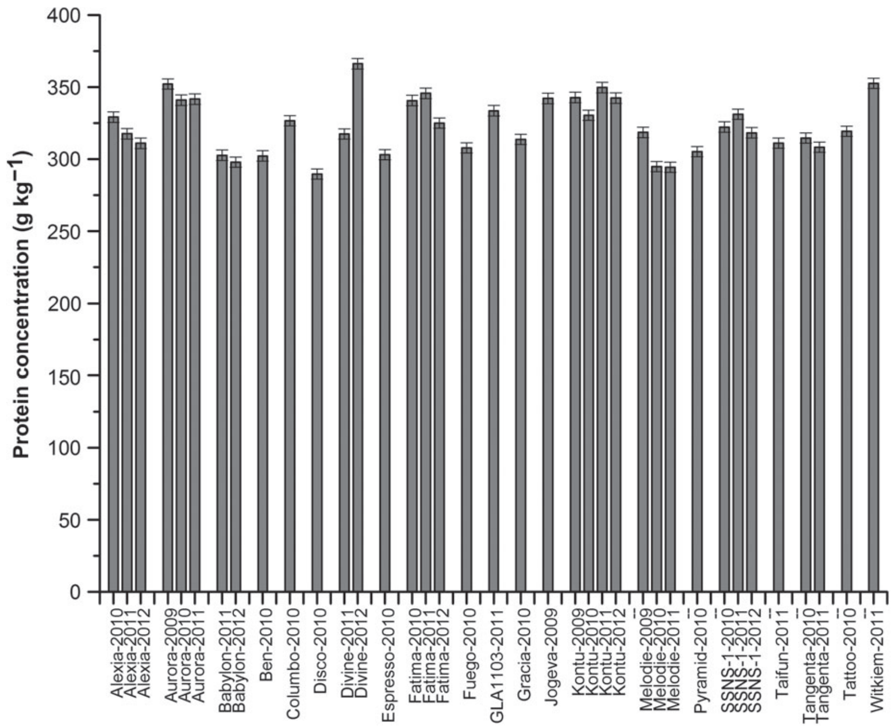

Figure 3. Seed protein concentration in faba bean cultivars screened during 2009–2012 in Helsinki.

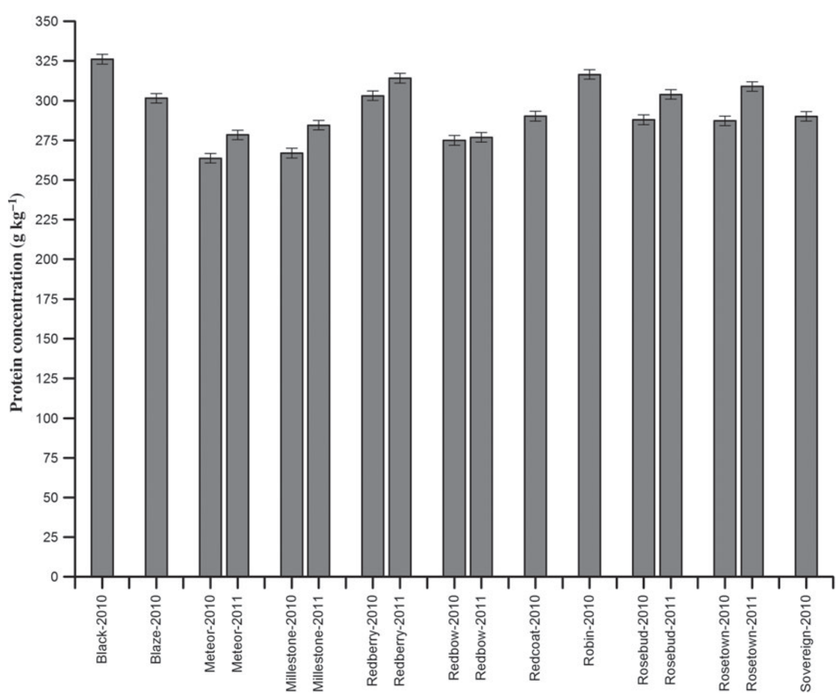

Figure 4. Seed protein concentration in lentil cultivars screened during 2009–2011 in Helsinki.

Effect of earliness, yield and seed size on protein yield

Yield and protein yield were positively correlated with growing degree days to maturity in both faba bean and narrow-leafed lupin, but the correlations were significant only in the latter, while negative and non-significant in lentil (Figs 6–8, parts A and B).

Seed size and protein yield had a non-significant negative correlation in faba bean and lentil, but in narrow-leafed lupin there was a significant and positive correlation (Figs 6–8, part C).

As found in most crops, there was a negative correlation between yield and protein content in faba bean and lentil, while it was positive in narrow-leafed lupin, although none of these correlations was significant (Figs 6–8, part D).

Fatty acid composition

There were significant differences between species in the concentrations of each fatty acid ($P < 0.001$) during 2011, and, as

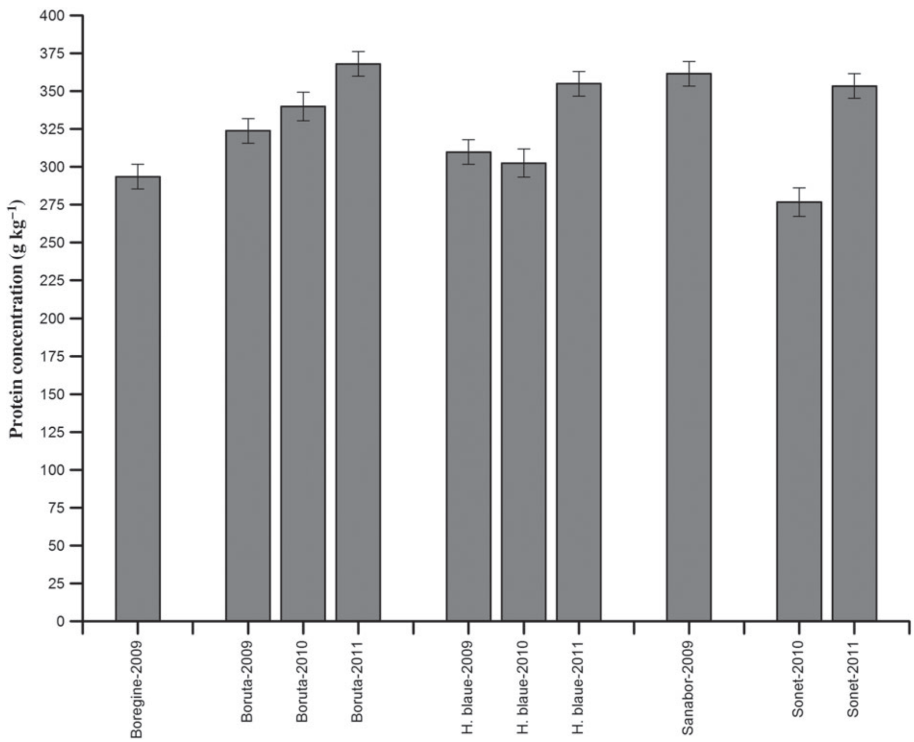

Figure 5. Seed protein concentration in narrow-leafed lupin cultivars screened during 2009–2011 in Helsinki.

expected, fatty acid concentration was higher in narrow-leafed lupin than in the other two species (Table 5).

The concentrations of each fatty acid differed between the four faba bean cultivars and the three years ($P < 0.001$), except for stearic acid (18:0) ($P > 0.05$), and there was a significant year × cultivar interaction for all fatty acids except stearic, arachidic (20:0) and gadoleic (20:1) acids (Table 6).

Variation in seed size and seed coat thickness in faba bean

'Kontu' had the smallest seeds and the thinnest seed coat (Table 7). Seeds of all cultivars were largest in 2009 and smallest in 2010, but 'Mélodie' showed little difference between 2010 and 2011. There were significant differences between cultivars and years ($P < 0.001$) and a significant year × cultivar interaction for this trait ($P < 0.01$). Although seed coat thickness did not vary significantly across years, the % of volume in seed coat was significantly different across cultivars and years ($P < 0.001$) and thus there was a significant year × cultivar interaction ($P < 0.01$).

DISCUSSION

The present study shows that it is feasible to cultivate appropriate cultivars of faba bean, lentil and narrow-leafed lupin in boreal climates, particularly that of Finland.

Although lentil can mature earlier than the other two species, its protein yield is low and management practices need to be developed in order to stop indeterminate growth and promote maturity in this high-value food crop. Moreover, it was clear that although faba bean had the highest yield potential, earlier germplasm is still needed, whereas narrow-leafed lupin was early enough but greater yield was required, as its mean yield was 60% and protein yield 68% of those of faba bean (Table 3).

The Sielianinow hydrothermal index is little used outside Poland, and the present results show that it is a useful way of indicating potential water deficit, particularly when calculated on a running basis.

Protein concentration and nutritive quality

The three grain legumes screened had a satisfactory chemical composition, showing that not only yield but good quality can be achieved in the boreal climate. Lentil protein, starch and ash contents were in agreement with those of lentils grown in western Canada, whose protein concentration ranges between 24.3 and 30.2% and starch concentration between 41.5 and 46.5%.[25] Faba bean protein concentration was on average one-sixth higher and starch concentration correspondingly lower than those achieved in Germany,[26] and the protein concentration was about one-tenth higher than in Sweden.[27] Protein concentration was within the range (26–38%) produced in tannin-containing and tannin-free French cultivars, but starch concentration was marginally lower.[28] The comparatively low starch concentration found in Finnish-grown faba beans may partly be due to the water deficit in two of the years, along with high temperatures in 2011, both of which are known to reduce starch deposition in many species.[29,30]

The mean protein concentration of narrow-leafed lupin was slightly higher than the Australian average of 32%, while fat content was approximately the same.[31] The protein concentration was also similar to values from the UK and Poland, while fat content was slightly higher than that of UK lupins[32] but lower than that of lupins from Poland.[33]

Differences in protein concentration may be due to differences in nitrogen metabolism as well as in starch or non-starch polysaccharide metabolism. Most cultivars showed higher protein concentration in the warmer years, 2010 and 2011, than in the cooler years, 2009 and 2010. Protein synthesis in leaves of faba bean was

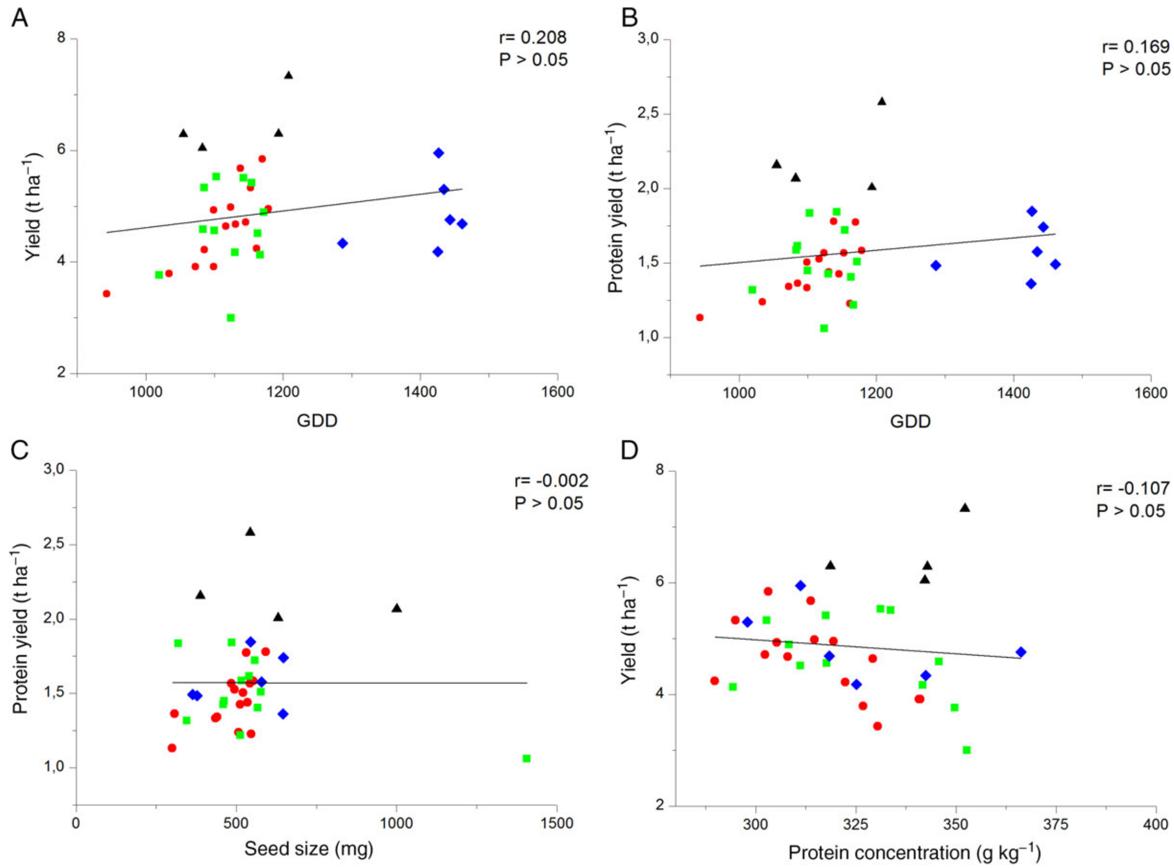

Figure 6. Correlation analysis of (A) yield and growing degree days to maturity (GDD), (B) protein yield and GDD, (C) protein yield and seed size and (D) yield and protein concentration for faba bean during 2009 (▲), 2010 (●), 2011 (■) and 2012 (◆).

promoted by high light intensities.[34] Changes in temperature and moisture during seed filling influence the C and N allocation: the rates of N accumulation in pea can increase owing to high temperatures in the reproductive phase,[35] and water deficits during seed development usually increase the amino acid concentrations in chickpea[36] and N remobilization to seeds of common bean.[37]

The negative correlation found between yield and protein concentration in faba bean and lentil agrees with reported similar trends in pea and lentil.[38] In contrast, narrow-leafed lupin had a unique positive correlation for these parameters owing to the high protein content of the high-yielding, late-maturing cultivars. Our experiments also indicated a significant cultivar effect on the protein yield of faba bean and narrow-leafed lupin but not for lentil, probably because of the relatively low genetic diversity in the lentil collection, all but one of which were from the same breeding program. Nevertheless, the cultivar × environment interaction on protein yield was significant in lentil as well as in faba bean, suggesting that there was genetic diversity for environmental response even in the relatively non-diverse lentil collection. The cultivar × environment interaction on protein yield was not significant in the narrow-leafed lupin cultivars, probably because only three were grown in more than one year.

As suggested in previous studies on pea and lentil,[38] it is clear from our screening trial that protein concentration in all three species depended more on cultivar than on environment. Part of this stability is attributable to biological nitrogen fixation capacity, which allows the plants to maintain their nitrogen uptake regardless of variation in soil nitrogen supply.

Protein and amino acid composition

Globulins account for about 50–90% of the storage protein in most grain legumes[39] and are generally divided into the 7S vicilins (conglutin β in lupins) and 11S legumins (conglutin α in lupins). Conglutin γ of lupins, a basic 7S protein, is of interest because of its high concentration of the sulfur-containing amino acids cysteine and methionine,[40] and, in our experiments, narrow-leafed lupin was the species with the highest concentration of these two amino acids.

The ideal amino acid composition for human nutrition and that for livestock are very similar, but the required amounts for the latter are usually higher; for example, while lysine (the most limiting amino acid in cereals) requirement for humans is 30 mg kg^{-1} day^{-1},[41] for pigs it is approximately 20% higher and it has been difficult to agree on the precise level required.[42,43] The amino acid contents of grain legumes in our trial are mostly in agreement with values reported elsewhere; except that methionine was 19% higher in narrow-leafed lupin[44] and cysteine was 36% lower in faba bean.[25] The lower content of cysteine in faba bean grown in Finland should not be considered a disadvantage, since cysteine is produced from methionine in most monogastrics, including humans.[41]

Although, in comparison with soya bean meal, narrow-leafed lupin and, even more so, faba bean have a low content of tryptophan and sulfur amino acids,[44] the standardized ileal digestibility (SID) of both pea and faba bean by broiler chickens is not significantly different from that of soya bean.[45] In addition, there is a plethora of other studies showing that narrow-leafed lupin

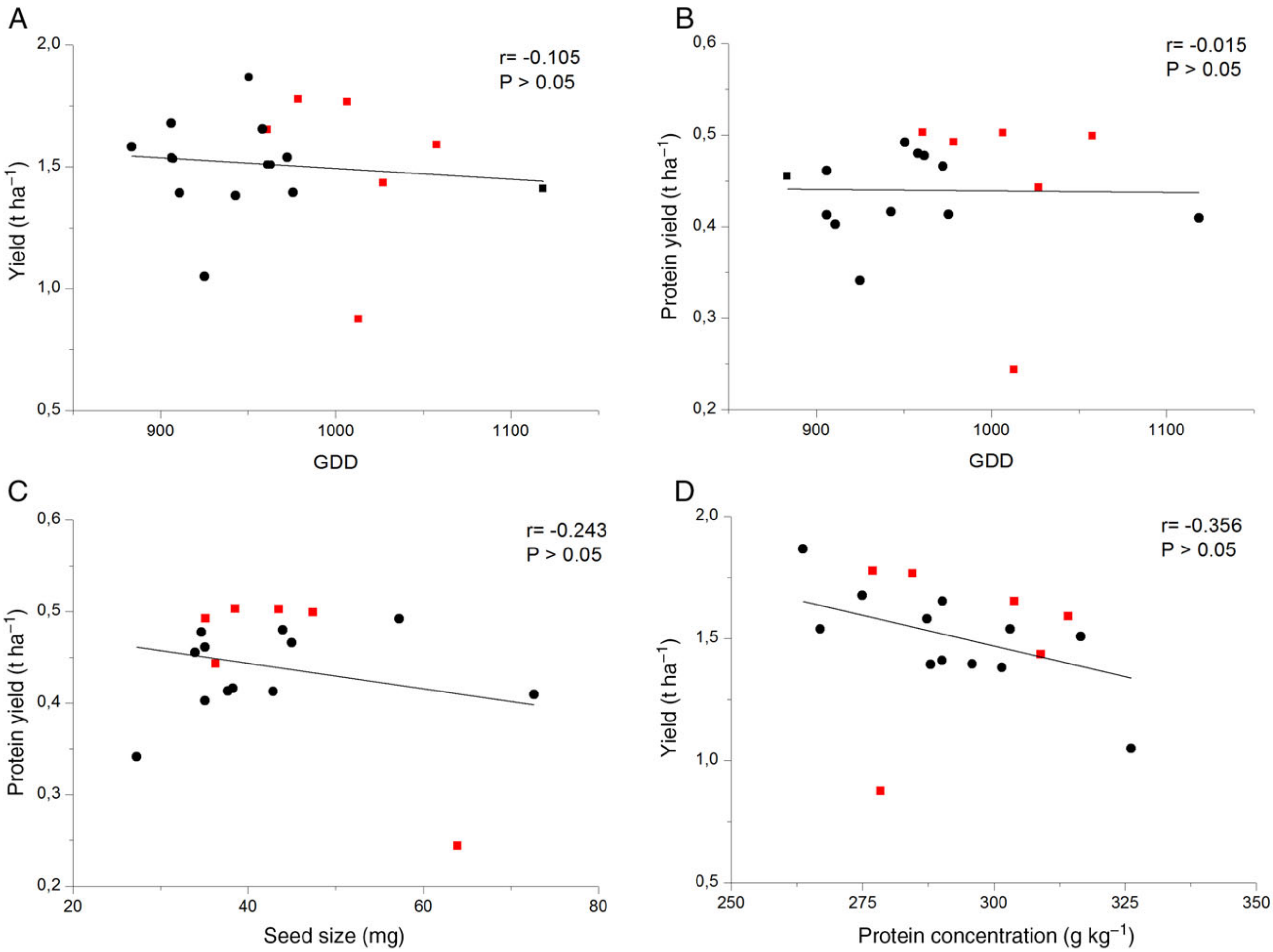

Figure 7. Correlation analysis of (A) yield and growing degree days to maturity (GDD), (B) protein yield and GDD, (C) protein yield and seed size and (D) yield and protein concentration for lentil during 2010 (●) and 2011 (■).

and faba bean can be used to partially replace soya bean meal in the diets of cattle,[46] fish,[47] turkeys[48] and broilers.[49] This clearly indicates that imported soya bean meal in key animal feeds can be at least partly replaced with home-grown grain legumes. In order for this to happen in an economically sustainable way, markets and value chains need to be developed and protein concentration needs to be improved.[50]

Fatty acid composition

The oil quality of the three legumes had a good level of linoleic acid (18:2n-6), which is one of the essential fatty acids for humans and animals.[51] Our results show that the fatty acid composition of narrow-leafed lupin is excellent, characterized by high levels of oleic, linoleic, linolenic, palmitic and stearic acids, making it an attractive ingredient for feed and nutraceutical products.

While the variation in fatty acid composition of faba bean cultivars was statistically significant, as was the cultivar × year interaction, the differences were small in biological and economic terms and unlikely to affect end-product usage or quality. The main outcome is that cv. Alexia had lower lipid content than the other three cultivars in all years.

Seed volume and seed coat thickness variation in faba bean

Seed size variation is of particular interest in faba bean, since this species shows a wider range of seed sizes than the other two. Seed coat thickness is an important parameter, because the seed coat comprises largely insoluble fiber and tannins, and so dehulling is often done to increase protein concentration and digestibility.[52] Although seed coat thickness was not significantly affected by year, there were important cultivar differences. Thin seed coat is implicated in the sensitivity of some chickpea cultivars to damage during handling ('bruising'). The lack of significant cultivar × environment interaction is advantageous, since it implies that dehulling operations can be standardized for any cultivar.

CONCLUSIONS

Narrow-leafed lupin is outstanding for its earliness and superior protein concentration; faba bean is advantageous for having the highest protein yield and high lysine content; lentil is an important specialty food crop that is suitable for short growing seasons. Thus the cultivation of each could be promoted depending on particular demands.

The protein concentration and overall nutritive quality of Finnish-grown grain legumes make them suitable for use as food and feed; the main challenge now is to increase their cultivation and to develop management practices. It is evident that the range of protein crops grown in boreal climates needs to be upgraded.

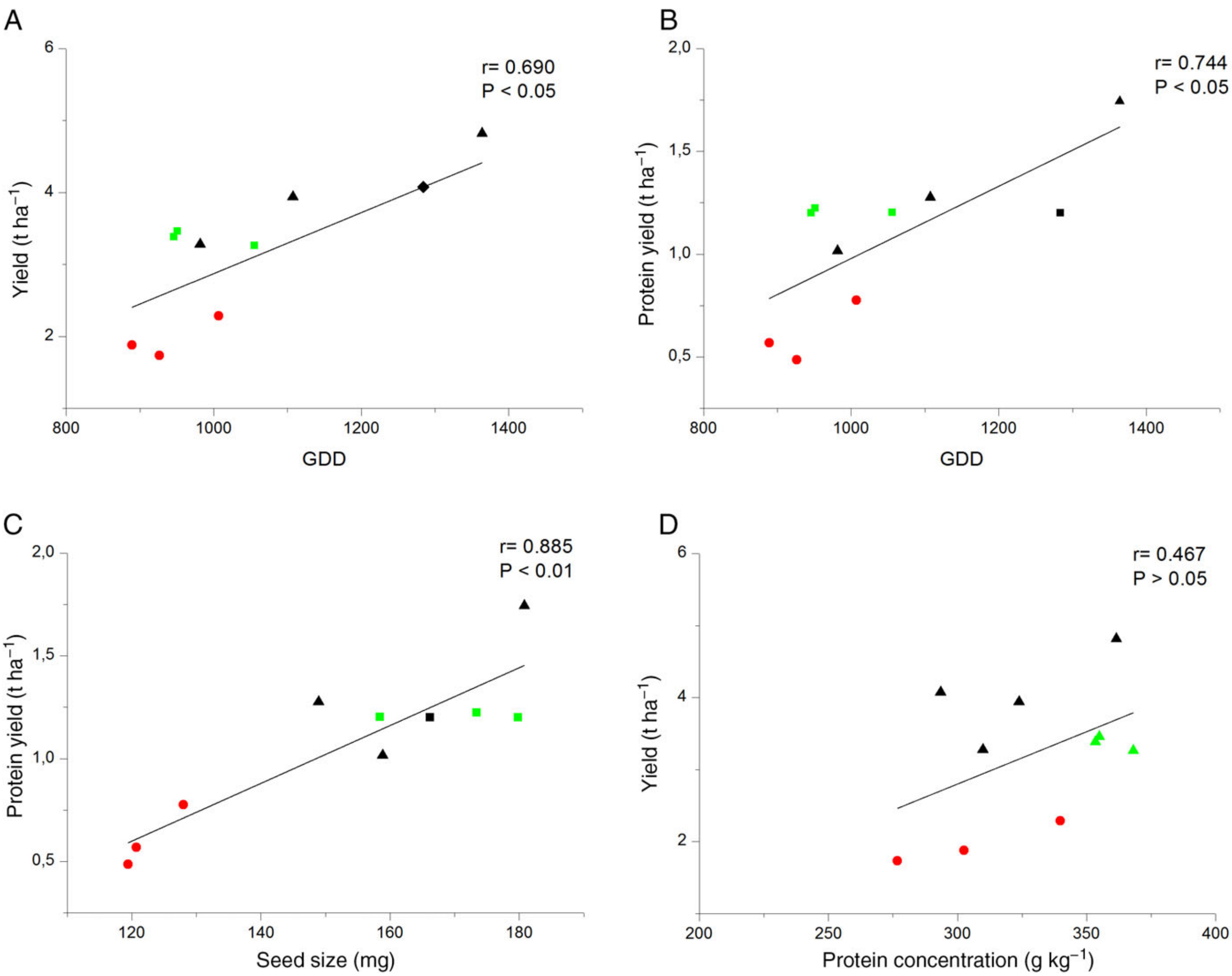

Figure 8. Correlation analysis of (A) yield and growing degree days to maturity (GDD), (B) protein yield and GDD, (C) protein yield and seed size and (D) yield and protein concentration for lupin during 2009 (▲), 2010 (●) and 2011 (■).

Table 5. Fatty acid composition (mg g^{-1}, dry weight basis) for faba bean, lentil and narrow-leafed lupin grown in Helsinki during 2011

	Faba bean		Lentil		Narrow-leafed lupin	
Fatty acid	Content	SD	Content	SD	Content	SD
16:0	1.58	0.13	1.49	0.04	5.51	0.12
18:0	0.29	0.02	0.20	0.02	4.07	0.52
18:1n-9	3.25	0.40	2.75	0.13	21.32	0.92
18:2n-6	6.87	0.50	5.63	0.46	19.27	1.11
18:3n-3	0.57	0.07	1.68	0.11	2.91	0.12
20:0	0.16	0.05	0.07	0.11	0.39	0.05
20:1	0.09	0.05	0.15	0.12	0.24	0.19
22:0	0.07	0.01	0.10	0.03	1.28	0.01
Total	12.87	0.87	12.07	0.64	55.00	0.92

Values are mean of 12 cultivars for faba bean and of two cultivars each for lentil and narrow-leafed lupin. SD, standard deviation.

Table 6. Fatty acid composition (mg g^{-1}, dry weight basis) of four cultivars of faba bean grown in Helsinki during 2010–2012

		Fatty acid								
Year	Cultivar	16:0	18:0	18:1n-9	18:2n-6	18:3n-3	20:0	20:1	22:0	Total
2010	Kontu	1.61	0.28	2.62	6.80	0.65	0.17	0.08	0.08	12.30
	SSNS-1	1.43	0.29	2.45	6.53	0.58	0.16	0.08	0.07	11.58
	Alexia	1.32	0.23	1.99	5.51	0.49	0.13	0.07	0.06	9.78
	Fatima	1.53	0.25	2.42	6.68	0.60	0.17	0.08	0.07	11.79
	SE	0.03	0.01	0.07	0.16	0.02	0.01	<0.01	<0.01	0.29
2011	Kontu	1.72	0.28	3.49	7.30	0.66	0.18	0.10	0.08	13.80
	SSNS-1	1.53	0.28	2.71	7.12	0.61	0.17	0.09	0.07	12.59
	Alexia	1.39	0.27	2.84	6.09	0.50	0.13	0.08	0.05	11.35
	Fatima	1.49	0.27	2.80	7.03	0.59	0.15	0.10	0.06	12.50
	SE	0.04	<0.01	0.09	0.14	0.02	0.01	<0.01	<0.01	0.26
2012	Kontu	1.77	0.26	4.01	7.86	0.64	0.18	0.11	0.08	14.94
	SSNS-1	1.66	0.27	3.76	8.09	0.60	0.17	0.11	0.08	14.74
	Alexia	1.43	0.27	3.75	6.71	0.47	0.13	0.10	0.05	12.90
	Fatima	1.69	0.30	3.96	7.73	0.55	0.19	0.11	0.09	14.62
	SE	0.04	<0.01	0.04	0.16	0.02	0.01	<0.01	<0.01	0.25

SE, standard error.

Table 7. Seed mass, % of volume in seed coat and mean seed coat thickness of faba bean seeds harvested during 2009–2011

	Whole seed volume (mg)			% of volume in seed coat			
Cultivar	2009	2010	2011	2009	2010	2011	Mean thickness (μm)
Kontu	388	300	345	5.2	5.4	5.3	70
Aurora	544	434	460	6.0	6.4	6.3	91
Melodie	631	542	513	6.3	6.7	6.6	101
SE		11			0.4		4

SE, standard error.

Each of the grain legumes included in the present study has shown its potential to be grown as a protein source for different feed and food products in the southern part of the European boreal zone. This potential is still hardly tapped, as shown by the low areas devoted to grain legume cultivation in the European boreal zone in contrast to the Canadian one. Advances in breeding for earliness and stress resistance will increase this potential and allow the expansion of grain legume cultivation further north in the boreal region.

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