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Lentil (*Lens culinaris* L.) cultivation in Sweden: possibilities and challenges

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ABSTRACT
Swedish lentil cropping is today limited to heritage and small-scale farming. As lentils can be grown on all types of soils with standard agricultural equipment and act as a break crop in grain dominated rotations, they have come into focus for commercial production. Knowledge on cultivar choice, seeding time, possibilities for intercropping, and weed control is crucial for increased cropping. Thus, field trials combined with climate chamber experiments have investigated suitable cultivars and temperature effects on emergence. Moreover, seed rates, intercropping lentils with oats and wheat, and weed control have also been studied. Modern lentil varieties can be cropped in Sweden, typically yielding 1.5–2 MT ha^{-1} with a top-level yield of 3.5 to 4 MT ha^{-1}. Intercropping with oats or spring wheat does not usually increase lentil yield. Lentil seed rates should not be less than 300 viable kernels m^{-2}. Early seeding should be avoided as low soil temperature (8–10°C) prolongs emergence. Initial trials on suitable herbicides for Swedish conditions have shown that annual weeds are able to be controlled sufficiently. In general, there are small differences in crop performance in different fields and cultivar choice should be based on the features desired by the food industry.

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Cold temperate conditions; cultivar choice; pulse crop; sustainable agriculture; weed control

Introduction

There is growing interest in plant proteins as a partial or full replacement for animal protein, and pulse crops are of particular interest in meeting this demand. In this respect, lentils (*Lens culinaris* Medik.), as a reasonably priced 'high-quality protein source', are gaining more and more attention (Yadav et al. 2007; Cokkizgin and Shtaya 2013). Globally, lentil production has increased fivefold since 1980 (FAOSTAT 2023). Approximately 5 million tons of lentils are produced annually but with relatively large annual variations. An early study by Arrhenius (1862) showed the potential for lentil cropping in Sweden but did not inspire farmers to put lentil cropping into practice. However, more than a century later, lentils are gaining attention as a new potential pulse crop for use as feed and food and, like other legumes, a means of adding nitrogen to the soil through symbiotic association with the rhizobia.

Assessing Sweden based on climatological conditions, it appears to be possible to grow lentils in Sweden, due to them being a cool-season or temperate crop. A recent study by Minkevicius et al. (2020) has shown that lentils were grown in the Baltic region as early as the Bronze age (around 1100 BC). Swedish winter temperatures are around 0°C and the typical growing season in southern Sweden, with temperatures above 10°C for around 220 days, is favourable for lentil production. These conditions can be compared with one of the main global producers of lentils, Saskatchewan, Canada, which is one of the coldest regions in Canada with winter temperatures around −20°C and summer temperatures from 15°C in May to the mid-30s in July and August.

In Saskatchewan, the cultivation of lentils was introduced as an alternative to grain in the 1960s. Since then, considerable effort has gone into developing optimal lentil cultivation systems. As Sweden has very similar climatological conditions to Saskatchewan, it is a good starting point to make use of the experience that has been built up there over fifty years of cultivation (Nleya et al. 2016). Experience of management practices such as soil requirements, land preparation, time of seeding, seed quantity, need for inoculation, row spacing, intercropping, harvesting technique, fertilisation and control measures should be transferable to Swedish conditions (Anon. 2023a, 2023b).

It is evident that weed control is of major concern when growing lentils. The challenge is even greater in organic cultivation systems. In such cultivation

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systems, indirect strategies, such as crop rotation, clean seeds, different seed varieties, primary tillage, changes to sowing date and crop density, and mixed cropping systems are important. By increasing crop density and increasing the share of companion crops, weeds can be suppressed without a major decrease in lentil yield (Erskine et al. 1990; Boerboom and Young 1995; Ball et al. 1997; Gruber et al. 2012). In Canada, organic farmers are recommended to increase the seeding rate of lentil to 229 plants per m^2 instead of the recommended 130 plants per m^2 in conventional systems (Baird et al. 2009). Two appropriately timed mechanical weed control methods in organically grown lentil fields in Canada, rotary-hoeing and inter-row cultivation, were able to reduce weed biomass by 70% and increase lentil yield by 65% (Alba et al. 2020). Inter-cropping has presented benefits; Wang et al. (2012) showed that under organic management, lentils under mixed cropping were superior to mono cropping by 5–40% with respect to land equivalent ratio, with lentil-barley and lentil-wheat being the most efficient. However, in a participant-driven study with 25 German lentil growers, it emerged that neither variety (Anicia, Späth's Alblinse I and II) nor intercrops (spring barley, oats, camelina) affected lentil yield (Reif et al. 2021).

Today, Swedish commercial lentil production is limited to one heritage cultivar, 'Gotlandslins', cropped on the island of Gotland in the Baltic Sea. The farmers obtain the seeds from a domestic food company that also purchases the crop for food production. Beside this production, amounting to about 25 hectares, only a handful of small-scale farmers in the southern Sweden have included lentils in their production, typically covering 0.5 ha or less. An overall issue for farmers is the lack of knowledge on varieties suitable for Swedish conditions, possible seed suppliers and prediction of yields. Adapting international seeding times and seed amount recommendations to Swedish conditions is also crucial for the development of commercial production. Moreover, effective weed control has been identified as a major challenge for increased cropping of lentils. The lack of registered herbicides, limited knowledge on weed control effects and possible damage to crop plants by physical and chemical methods hampers production and the willingness to include lentils in crop rotations.

In order to provide Swedish agriculture with information about key-issues on lentil cropping, our study aimed to: (i) Investigate the effect of soil and air temperature on the germination of lentils; (ii) Compare the yield of selected lentil varieties in field trials; (iii) Investigate the effect of pure vs intercropped stands on lentil yield; and (iv) Determine the optimal seeding rate for lentil production and determine its effect on yield. To complement this, the initial field trials of potential herbicides for use in Swedish commercial lentil cropping is included.

Material and methods

Selection and acquisition of lentil seeds

Commercial lentil seed is hard to obtain through Swedish seed companies due to a lack of customers and little knowledge on suitable cultivars. Thus, seeds were acquired from French (www.qualisol.fr) and Polish (www.nasiona-warzywa.pl) seed suppliers, through international scientific collaboration (University of Saskatchewan, Canada) and from a Swedish food company (www.nordiskravara.se). We aimed to use commercial seeds of different sizes (expressed as differences in TKW), seed coat colours and origins. Seed multiplication of the varieties 'Greenland', 'Kermit' and 'Redberry' is not allowed outside of Canada. New seeds could not be obtained for trials in 2021 and 2022, but surplus seeds saved as reference samples made it possible to at least partially include Canadian varieties in the Halland trial in 2021.

Cultivar characteristics are described in Table 1.

Early emergence experiments

Five of the cultivars used in the 2020 field trials were selected for growth temperature experiments in climate chambers at SLU, Uppsala, starting in January

Table 1. General description of the tested cultivars.

Cultivar	TKW (g)	Seed coat colour	Seed origin	Seed supplier
Anicia	32	Blonde	France	Groupe Qualisol, France
Anita	47	Olive green	Poland	PlantiCo, Poland
Beluga noire	18	Black	France	Groupe Qualisol, France
Flora	27	Blonde	France	Groupe Qualisol, France
Gotlandslins	31	Black-red-brown	Sweden	Nordisk råvara AB, Sweden
Greenland	70	Olive green	Canada	Univ Saskatchewan, Canada
Kermit	37	Green	Canada	Univ Saskatchewan, Canada
Redberry	47	Reddish	Canada	Univ Saskatchewan, Canada
Rosana	23	Reddish	France	Groupe Qualisol, France
Tina	48	Olive green	Poland	PlantiCo, Poland

Table 2. Seeding and harvest dates.

	2020		2021		2022	
Site	Seeding	Harvest	Seeding	Harvest	Seeding	Harvest
Öland	May 11th	August 24th	–	–	May 5th	August 12th
Halland	–	–	April 28th	August 26th	May 6th	Sept 1st
Skåne	–	–	–	–	May 2nd	August 16th

2021. The cultivars 'Anita', 'Beluga noire, 'Gotlandslins', 'Greenland' and 'Redberry' were selected based on their performance in the 2020 field trial, their seed size, colour and origin to represent interesting phenotypic traits for commercial production in Sweden. As the number of available climate chambers was limited, the temperature series had to be divided into two separate experiments. In the first experiment, four temperatures were used, one for each chamber: 10°C, 15°C, 18°C and 22°C, respectively. The second experiment used temperatures of 8°C, 10°C, 12°C and 15°C. Temperature was not altered during the experiment period and light was present for 12 h for each 24 h.

Round metal trays (Mitscherlich pots) were filled with a commercial peat/pumice mixture from Hasselfors Garden AB. (Såjord S). In each tray, 20 seeds of one of the selected cultivars were placed randomly; these were then covered with soil, irrigated with tap-water and kept moist during the experiment. Four trays of each cultivar were placed in each chamber (temperature), randomly distributed on four shelves.

Seeding took place in January 2021 and the number of emerged plants in the trays were counted 7, 10 and 14 days after seeding. The second experiment was established in February 2021 using the same design, cultivars, and assessment times (days after seeding) as the first one.

Field trials

Field trials were conducted at two main sites: (i) on the island of Öland in the Baltic Sea using the field experimental station of Kalmar-Kronoberg Hushållningssällskap at Torslunda, (hereafter referred to as 'Öland' (E 16° 30′; N 56° 37′)), and (ii) the Lilla Böslid experimental station (hereafter referred to as 'Halland' (E 12° 56′; N 56° 35′)) of Hallands Hushållningssällskap, located on the Swedish west coast. In 2022, one field trial (herbicide trial) was conducted in the province of Skåne in southern Sweden (hereafter referred to as 'Skåne' (E 13° 5′; N 55° 53′)) operated by Hushållningssällskapet Skåne, a regional field experiment and advisory service organisation like the previously mentioned organisations.

All field trials were carried out using a randomised complete block design with four repetitions for all treatments.

Plot yields were dried at the trial sites and later transported to RISE in Uppsala. Seeding and harvest dates are given in Table 2.

The soil at the Öland site had a pH of 6.4 and is classified as a moderately humus-rich loamy sand with a clay content of 8% and organic matter of 4.0%. The region is characterised by low precipitation (400–500 mm annually), an early spring, and sunny, warm summers.

The soil at the Halland site had a pH of 6.0 and is classified as a loamy sand with a clay content of 9% and organic matter of 3.6%. The region is characterised by high precipitation (800–1300 mm annually), an early spring, and sunny, warm summers.

The soil on the trial site in the province of Skåne had a pH of 6.4 and is classified as a loamy sand with a clay content of 15% and organic matter of 3.6%. The region is characterised by medium precipitation (600–900 mm annually), an early spring, and warm summers. Mean temperatures, precipitation and degree days for the test sites during the cropping period are given in Table 3.

Field trials in 2020

Two field trials were conducted at Öland in 2020; one trial used the ten varieties described above in pure stand, and the other used the same ten varieties in a seed mixture (additive design) with spring oats (*Avena sativa*, 50 kg seeds ha^{-1} equivalent to 115 kernels m^{-2}) added.

The lentil varieties were seeded in plots of 1.75 × 12 metres, with a row distance of 25 cm and a seeding depth of about 3 cm. Mineral fertilisers (PK-11-21, 190 kg ha^{-1} in combination with NS 27-4, 150 kg ha^{-1}) were applied prior to seeding. The seed rate of lentils was about 300 kernels m^{-2}.

Weed control was carried out using a pre-emergence herbicide (Centium 0.4 l ha^{-1}) followed by repeated in-row weed control and one hand weeding. The harvest from each plot was dried and stored in cotton bags.

Field trials in 2021

A field trial was conducted in Halland in 2021, focussing on the yield effects of mixed stands with either oats

Table 3. Precipitation (mm), mean temperatures (°C) and growing degree days (GDD) using +5°C as base, at test sites during cropping period.

	2020			2021			2022		
Site	Prec.	Temp	GDD	Prec.	Temp	GDD	Prec.	Temp	GDD
Öland	86	15.3	1034	–	–	–	63	16.6	1147
Halland	–	–	–	209	15.7	1082	89	15.9	1063
Skåne	–	–	–	–	–	–	156	19.0	1392

(*Avena sativa*) or spring wheat (*Triticum aestivum*) compared to a pure stand.

Based on the results of 2020, five cultivars were selected for the field trial ('Anita', 'Beluga noire', 'Greenland', 'Kermit' and 'Tina'). These were selected based on seed skin colour and TKW to represent different types of lentils for the food industry.

The trial was designed as a complete randomised block experiment with four blocks. The selected varieties were seeded in plots of 1.75 × 12 metres, with a row distance of 25 cm and a seeding depth of about 3 cm. We used an additive design (300 + 115 seeds), that is the seed rate was about 300 kernels m^{-2} for the lentils and 50 kg ha^{-1} (approx 115 kernels m^{-2}) for oats and wheat, respectively. Prior to seeding, a mineral fertiliser (Yara NPK 21-3-10, 200 kg ha^{-1}) was applied. Weed harrowing (Einböck harrow at three times, May 19th, 21st and June 3rd) was used as a weed control method. Harvesting of the net plot (13.5 m^2) was carried out using a plot combine.

Field trials in 2022

In 2022, we carried out trials at three sites: Halland, Öland and Skåne. The latter site was operated by the regional advisory service organisation (Hushållningssällskapet Skåne) in cooperation with the farmer owned company Lantmännen.

In Halland, three field trials were carried out on: (i) seed amount, (ii) weed harrowing, and (iii) lentil/wheat mixtures. The trials were all designed as randomised complete block experiments with four repetitions, using a row distance of 25 cm and a seeding depth of about 3 cm. Mineral fertilisers were applied prior to seeding in combination with seed bed preparation. The seed rate was about 300 viable kernels m^{-2} of the lentils except in the seed amount trial. We used 50 kg spring wheat ha^{-1}, equivalent to about 115 kernels m^{-2} in the intercropping trial. A plot size of 1.75 × 12 m was used except in the weed harrowing trial (3.5 × 12 m) as the harrow had a working width of 3.2 m. Harvest plots were 15 m^2 in all trials. Harvesting was carried out using a plot combine.

In Öland, one cultivar trial with eight lentil varieties was carried out in a randomised complete block design with four replicates, using a net plot size of 15.75 m^2. The chosen cultivars were 'Anicia', 'Beluga noire', 'Flora', 'Kermit', 'Redberry', 'Rosana', 'Samos' and 'Tina'. The variety 'Samos' was included as part of an ongoing cooperation with the Swedish food industry; the results for this variety are not reported due to confidentiality agreements. Harvesting was carried out using a plot combine. Seeds were dried in cotton bags and cleansed by the authors.

In addition, pilot trials of suitable herbicides for weed control of annual weeds were carried out in Öland (the results of this are not included in this study due to confidentiality agreements) and in the province of Skåne using a randomised complete block design with four repetitions (a total of 40 plots). In the herbicide trials, nine herbicides or combinations of herbicides were tested for an overall indication of suitable treatments against annual weeds (Table 4). In these trials, visual assessment of phytotoxic damage to the lentil stand was carried out. Lentil yield was recorded in the Skåne trial. The trial used the cv 'Flora' originating from France. A plot size of 3 × 7 m was used, with a net plot of 15.75 m^2 for harvesting. Spraying of plots was carried out according to instructions from licensed herbicide representatives in Sweden; this varied between sites due to local weather conditions. Fertilisation, general field management and harvest time were synchronised with previously described trials at these sites.

Statistical analyses

The statistical analyses of all trials were carried out by the authors using the Statgraphics Centurion XVI software. Control of data distribution (Normal Probability Check) was carried out prior to further analysis. Multifactor ANOVA with Tukey's HSD was used as standard analysis. All observations and registrations were used in the statistical analyses. Results are presented as mean values. Statistical differences are presented as p-values using the 95% level as standard.

Results and discussion

Early emergence experiments

In both experiments, temperature had a significant ($p = 0.0001$) influence on seed emergence 7, 10 and 14 days

Table 4. Herbicides used in the pilot trials on the island of Öland and province of Skåne in 2022.

Common name	Active substance	Amount (L ha^{-1})	Treatment time	Comment
Centium 36 CS	Clomazon 360 g	0.25	Directly after seeding	–
Cleravo SC	Imazamox 35 g Quinmerac 250 g	1.0	Post emergence	Weeds at heart-leaf stage
Conaxis	Dimetenamid-p 400 g Clomazon 50 g	1.5	Directly after seeding	–
Corum + Dash	Imazamox 22.4 g Bentazon 480 g	0.625	Post emergence	Weeds at heart-leaf stage
Corum + Dash	Imazamox 22.4 g Bentazon 480 g	1.25	Post emergence	Weeds at heart-leaf stage
Fenix SC	Aclonifen 600 g	0.9	Directly after seeding	–
Fenix SC	Aclonifen 600 g	0.35	Post emergence	Weeds at heart-leaf stage
Lentagran WP	Pyridat 450 g	1.0	Post emergence	Weeds at heart-leaf stage
Tanaris	Dimetenamid-p 333 g Quinmerac 167 g	1.2	Post emergence	Weeds at heart-leaf stage

after seeding. Significant interactions between cultivar and temperature were also present in both experiments ($p = 0.0001$). In the first experiment, 72–94% of the cultivar seeds had germinated and emerged 7 days after seeding in 15°C for all seeds other than 'Redberry' (34%). Two weeks after seeding, 77–99% of seeds had emerged; again, 'Redberry' was an exception to this at 65% (Figure 1). Temperatures of 18°C and 22°C resulted in more or less full emergence (82–100%) 7 days after seeding, except for 'Redberry', which only reached 66–72% germination.

In the second experiment, no plant emergence was recorded in the lowest (8 and 10°C) temperatures 7 days after seeding (Figure 2). As in the first experiment, we recorded that temperature had a significant ($p = 0.0012$) influence on seed emergence 7, 10 and 14 days after seeding. Ten days after seeding, 'Greenland' and 'Gotland' both had emerged to 44%, while 'Anita', 'Beluga noire' and 'Redberry' were in an early phase of emergence between 0 and 11%. At a temperature of 12°C, emergence of 34% ('Greenland') was recorded 7 days after seeding and emergence of all cultivars except 'Redberry' rose to 85–95% ten days after seeding.

Both trials showed that 'Gotland' and 'Greenland' had the ability to reach 82–94% germination at 10°C after two weeks, which was somewhat better than the other cultivars (77–78%).

When temperature was increased to 12°C, all varieties had emerged to a level of 90–95% after 14 days.

The experiments showed that 'Gotland' and 'Greenland' were better adapted to cool soil and air temperatures for rapid germination compared with 'Anita' and 'Beluga noire'. 'Redberry' showed great variation in emergence between experiments, which might be connected to a requirement for higher soil temperatures or may be due to less viable seeds.

An applied outcome of the climate chamber experiments showed that soil temperature should exceed 10°C to ensure quick emergence and plant development, although some varieties are able to provide acceptable germination and emergence in temperatures as low as 8°C. This latter finding is vital from a Swedish farmers' perspective, as it guides choice of variety and field seeding dates.

Suitable varieties for Swedish conditions

The trials in 2020 were severely affected by annual weeds and the low yields reflect the problem with insufficient weed control. In pure stand, the yields of the ten varieties varied between 621 and 1054 kg ha^{-1} ($p = 0.49$), with 'Kermit' and 'Redberry' as the best yielding (Table 5).

In this trial, we experienced yields similar or somewhat better than in 2020 for 'Anicia' and 'Kermit', while 'Beluga Noire' excelled with an average yield of 1890 kg ha^{-1} (Table 5).

The Öland and Skåne trials in 2022 confirmed earlier results. Again, 'Beluga noire' and 'Kermit' yielded better than the other cultivars, in some cases above 4000 kg ha^{-1}, but the yield variations in fields were substantial, making it difficult to make clear recommendations for cultivar choice. We conclude that the climate at test sites, soil conditions, precipitation and weed control measures are crucial factors affecting yield.

The high yields in Skåne in 2022 (Table 5) indicate the yield potential when weed control is successful and soil/weather conditions are suitable. 'Beluga noire' yielded about 4000 kg ha^{-1} while 'Anicia', 'Rosana' and 'Tina' had yields of about 3500 kg ha^{-1}. In 2022, growing degree days (GDD) in Skåne were about 1300 compared to about 1000 recorded in previous years and test sites. The US website 'Pestprophet' (Anon. 2024) reports that, according to Montana State University models, lentils are ready for harvest at 3060 GDD (F), equivalent to about 1700 GDD using the Celsius scale. The warmer season in Skåne in 2022 might thus be a major

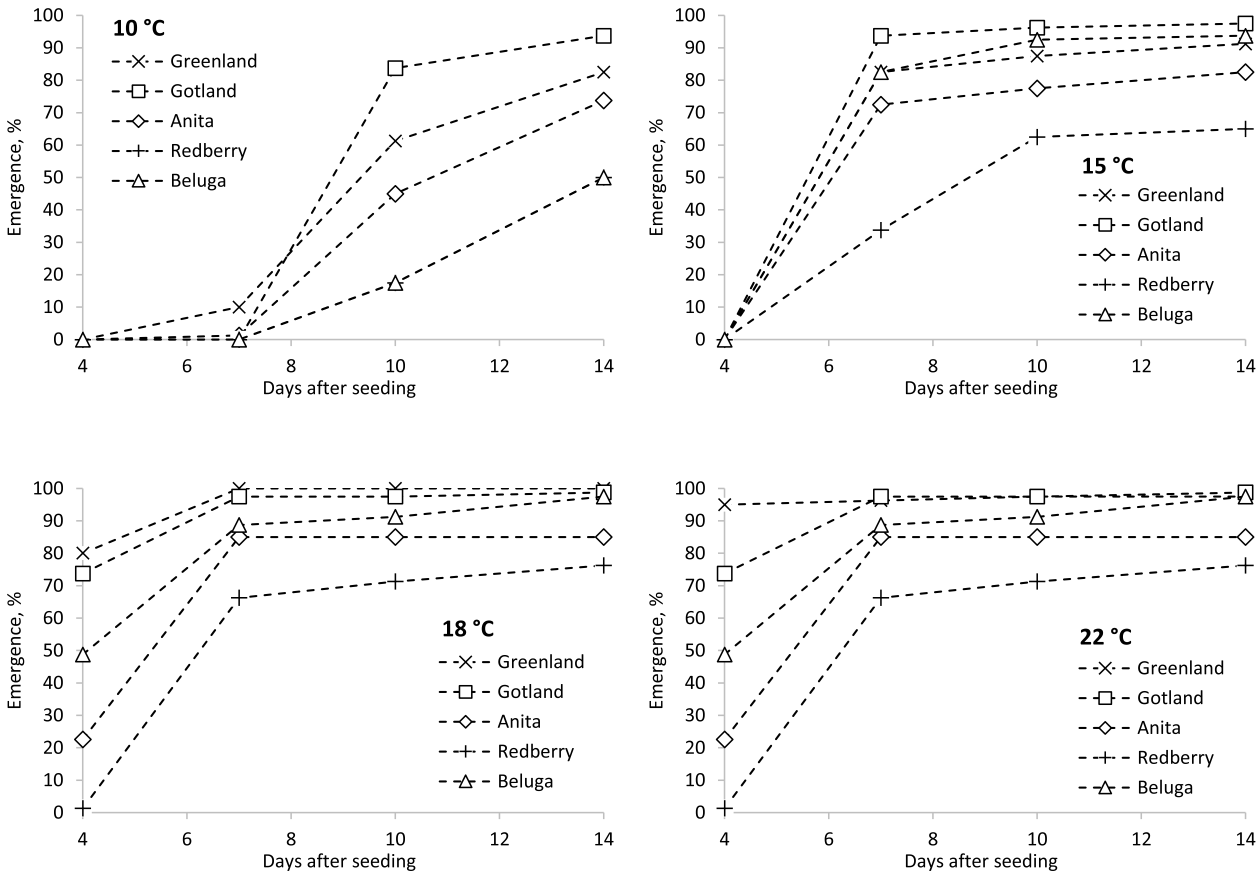

Figure 1. Emergence of five lentil cultivars grown in four (10°, 15°, 18°, 22°C) temperatures during a 14 day period.

contributor to the high yields. In turn, this raises questions about the possible benefits of early (mid-April) seeding in Sweden to increase the total heat sum during the cropping season.

Lentils intercropped with oats or spring wheat

A mixed stand of lentils and cereals (intercropping) is intended to suppress weeds, increasing yield and benefiting harvest as the lentil plants are supported by grain plants, thus reducing lodging. Recent studies (Jensen et al. 2020; Kraska et al. 2020) have shown that intercropping lentils with oats can reduce the yield of lentils by about 9% but will also suppress weeds. These studies have not discussed the technical effects of the mixed lentil-cereal stand on harvest. The lentil stand in our trials was typically 35–40 cm high and, in some cases, subjected to lodging. As standard combines often leave a stubble height of 10–15 cm, there is a risk of yield losses if the crop is lodged. Modern headers and 'flexi-headers' can be a technical solution as these are adapted to leave a low 3–10 cm stubble height. The advisory service organisations that carried out harvesting in 2020–2022 did not, however, report mixed stands resulting in lower seed losses at harvest compared to lentils in pure stands (Hushållningssällskapen, pers, comm, 2020–2022).

In the Öland trial 2020, 'Beluga noire' intercropped with oat had a significantly higher yield than 'Rosana' and 'Tina' ($p = 0.0057$); overall, however, there were no statistical differences between cultivars. Mixed stands with oats did produce generally lower yields compared to pure stands ($p = 0.014$) except in the case of 'Beluga noire' and 'Gotlandslins', for which yields were increased (Table 6). These findings could be the result of 'Gotlandslins' being able to germinate and emerge under cool soil temperatures, thus having a greater ability to compete with oats compared to late germinating lentil cultivars. 'Beluga noire' proved to be high yielding at all test sites, indicating that the cultivar is suitable for many types of soil conditions and seasonal variations. As 'Beluga noire' has only been cultivated in field trials in Sweden, we cannot currently attribute other phenotypic traits to its overall strong yield ability. 'Gotlandslins' is an old variety owned by a private food company. It is cultivated solely at conventional farms on the island of Gotland. Information of production details is not public. An even and rapid germination and good competitive ability might make this cultivar more suitable for mixed stands than the other lentils in the trial.

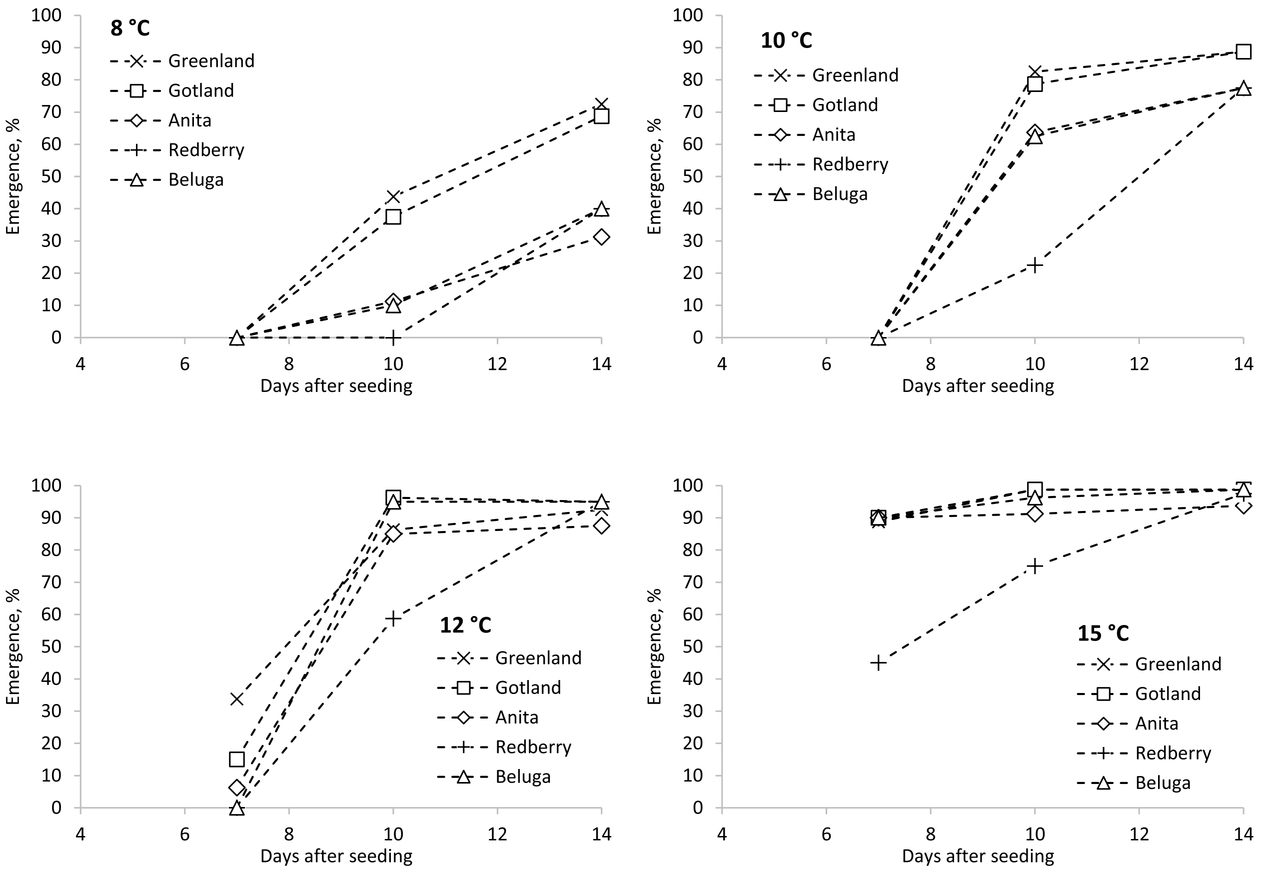

Figure 2. Emergence of five lentil cultivars grown in four (8°, 10°, 12°, 15°C) temperatures during a 14 day period.

The 2021 trial in Halland showed statistical differences of pure stand yields between cultivars ($p = 0.0001$) with 'Beluga noire' at the top with about 1500 kg ha^{-1} while 'Anita' and 'Tina' yielded below 1000 kg ha^{-1} (Table 7). Both oats and wheat tended to increase yields. These results partly contradict those from the trial in Öland in 2020. However, soil and weather conditions were different, and we improved weed control in Halland compared to the Öland trials. The weed biomass aspect was not studied in our field trials. Jensen et al. (2020) have shown that weed biomass is lower in an intercropped lentil-oats stand compared to a sole stand of lentils. Similar findings have been shown in Indian studies (Singh et al. 2011) and Polish studies (Kraska et al. 2020). There is no clear trend regarding the effect of grain type on lentil yield. An applied aspect of the choice of grain is the ability to cleans yield after harvest. In our case, the lentil-oat mixture demanded less work to separate as the seed difference is more pronounced than between lentils and wheat kernels.

Table 5. Marketable yields (kg ha^{-1}) of lentils in pure stands.

	Öland		Halland	Skåne	
Cultivar	2020	2022	2021	2022	2022
Anicia	759 a	1360 ab	–	–	3575 abcd
Anita	948 a	–	592 a	961 a	982 a
Beluga noire	809 a	2062 b	1181 b	1273 a	4087 cd
Flora	775 a	816 a	–	–	2669 a
Gotlandslins	621a	–	–	–	–
Greenland	763 a	–	426 a	–	–
Kermit	1055 a	2076 b	1111 b	–	4297 d
Redberry	1006 a	1316 ab	–	–	3522 abcd
Rosana	731 a	1435 ab	–	–	3270 ab
Tina	702 a	1287 ab	582 a	–	3367 abc

Note: Figures with the same letter(s) indicate that there is no statistical difference at the 95%-level using Tukey's HSD test.

Table 6. Marketable yield (kg ha^{-1}) of lentils at Torslunda, Öland, in either pure stand or intercropped with oats.

	Yield	
Cultivar	Pure stand	With oats
Anicia	759 a	520 ab
Anita	948 a	641 ab
Beluga noire	809 a	1108 b
Flora	775 a	673 ab
Gotlandslins	621 a	959 ab
Greenland	763 a	828 ab
Kermit	1055 a	912 ab
Redberry	1006 a	594 ab
Rosana	731 a	404 a
Tina	702 a	390 a

Note: Figures with the same letter(s) indicate that there is no statistical difference at the 95%-level using Tukey's HSD test.

Table 7. Marketable yields (kg ha^{-1}) of lentils in the Halland trials 2021 and 2022 either in pure stands or intercropped with oats or spring wheat.

		Yield	
Cultivar	Grain	2021	2022
Anita	–	592 ab	982 a
Anita	Oats	836 abc	–
Anita	Wheat	877 ab	951 a
Beluga	–	1180 cdef	1273 a
Beluga	Oats	1567 def	–
Beluga	Wheat	1704 f	1019 a
Greenland	–	426 a	–
Greenland	Oats	1575 ef	–
Greenland	Wheat	1068 bcde	–
Kermit	–	1110 bcde	–
Kermit	Oats	1213 cdef	–
Kermit	Wheat	997 abcd	–
Tina	–	582 ab	–
Tina	Oats	1076 bcde	–
Tina	Wheat	1012 bcde	–
Anita		768 a	966 a
Beluga		1484 c	1146 a
Greenland		1023 ab	–
Kermit		1107 b	–
Tina		890 ab	–
	–	778 a	1127 a
	Oats	1254 b	–
	Wheat	1131 b	985 a
P_{grain} [a]		0.0001	ns
	$P_{cultivar}$ [a]	0.0001	ns
$P_{inoculation}$ * $P_{cultivar}$ [a]		0.0021	ns

Note: Figures with the same letter(s) indicate that there is no statistical difference at the 95%-level using Tukey's HSD test.
[a] *P*-values show probability values for the factors grain type and cultivar and the interaction between these two factors.

In the 2022 trial in Halland, we selected two cultivars ('Anita' and 'Beluga noire') for cropping with or without spring wheat. The lentil yields varied from 951 kg ha^{-1} to 1273 kg ha^{-1} without any statistical differences between the treatments ($p = 0.079$), likely due to weed infestation.

In contrast to 2021, in 2022, there were no overall differences between lentils in pure stands (1 127 kg ha^{-1}) compared to wheat-mixed stands (985 kg ha^{-1}).

A mixed stand using a cereal crop such as oats or wheat, would theoretically be beneficial for the weak lentil plant, minimising lodging, weed competition and possibly reducing bird damages. In the 2021 trial, we found a statistically significant interaction between cultivar and use of intercropping ($p = 0.0021$) in terms of increased yields in the mixed stands compared to pure stands. The varieties 'Greenland' and 'Tina' seemed to, in general, benefit from being intercropped with both oats and wheat. These yield increases might be an effect of the grain crop's ability to suppress weeds, favouring lentil plants. An observation was that the yield increase was not as pronounced in 'Beluga noire'. This variety yielded 1.2 to 1.7 MT ha^{-1}, appearing to withstand weed competition better than the other four varieties (Table 7). As shown in the climate chamber experiments, 'Beluga noire' could in reach 95% emergence 12 days after seeding in 12°C, compared to about 85% emergence of 'Anita' and 'Greenland'. The higher yields of 'Beluga noire' compared to other cultivars might be an effect of earlier germination and faster emergence, resulting in a greater ability to withstand weeds and less need for supporting grain crop to excel. Lentils typically have a plant stand height of 30–40 cm and a thin canopy, which unfortunately makes it susceptible to weed competition. Our study did not include measurements of differences between varieties in lentil-weed competition, but rapid lentil emergence, a dense canopy and narrow row distances will enhance weed competition for the lentil stand.

Table 8. Visually estimated weed cover after weed harrowing in combination with herbicide treatment and marketable yields (kg ha^{-1}) of lentils.

	Weed cover after treatment (%)			
Treatment	2 weeks	4 weeks	6 weeks	Yield
Centium	35 a	20 a	27 a	1 248 a
Centium + 1 harrowing	34 a	20 a	17 a	1 158 a
Centium + 2 harrowings	22 a	13 a	19 a	1 045 a

Note: Figures with the same letter(s) indicate that there is no statistical difference at the 95%-level using Tukey's HSD test.

Weed control

Although herbicides (Centium, 0.4 kg ha^{-1} preemergence) were used in the field trials, we experienced severe problems with weeds such as *Chenopodium album, Veronica sp. Cirsium sp.* and *Echinocloa crus-galli*. The trial in Halland with herbicides (Centium 0.4 kg ha^{-1} preemergence), either as a single treatment or in combination with one or two weed harrowings, was designed to evaluate the effect of a combination of chemical and physical weed control methods. Visual assessment of weed coverage 2 weeks ($p = 0.457$), 4 weeks ($p = 0.150$) and 6 ($p = 0.154$) weeks after

Table 9. Marketable yields (kg ha^{-1}) obtained in the Skåne trial in 2022 using cultivar 'Flora' treated with nine different herbicides.

Common name	Yield	Amount herbicide (L ha^{-1})	Treatment time
Centium 36 CS	4 999 c	0.25	Directly after seeding
Cleravo SC	4 754 c	1.0	Post emergence
Conaxis	4 986 c	1.5	Directly after seeding
Corum + Dash	2 705 b	0.625	Post emergence
Corum + Dash	1 086 a	1.25	Post emergence
Fenix SC	4 859 c	0.9	Directly after seeding
Fenix SC	4 719 c	0.35	Post emergence
Lentagran WP	4 700 c	1.0	Post emergence
Tanaris	4 665 c	1.2	Post emergence
Untreated	4 837 c	–	Untreated

Note: Figures with the same letter(s) indicate that there is no statistical difference at the 95%-level using Tukey's HSD test.

harrowing only showed non-significant differences between weeding treatments. Damage to the lentil plants by weed harrowing were not recorded. There were no statistical differences ($p = 0.7167$) in yields between the three treatments, indicating that any of the strategies could be possible (Table 8) but not sufficient to control the annual weeds fully.

The herbicide trials in 2022 (Table 9) showed that a combination of Corum (22.4 g L^{-1} Imazamox + 480.0 g L^{-1} Bentazon) and Dash HC adjuvant was unsuitable as this combination reduced lentil stand at both sites (Öland results not presented due to a confidentiality agreement). In the Skåne trial, lentil yield was reduced by 44–75% using Corum + Dash, compared to the mean yield obtained in the other herbicide treatments ($p = 0.0001$). Except for in the Corum + Dash treatments, no significant yield differences were recorded between herbicide plots and the control plot in the Skåne trial ($p = 0.524$).

The effect on weeds varied between treatments and sites. The tested herbicides show promising results (70–100% control compared to non-treated) regarding the control of annual weeds common for Sweden (*Chenopodium album, Thlaspi arvense, Capsella bursa-pastoris, Viola arvensis and Fallopia convolvulus*). It should be noted here that herbicide use must be adapted to the local weed flora, soil types and weather conditions.

Under temperate conditions, autumn and spring pre-seeding tillage should be early enough to allow weed emergence and control before seeding of the lentil crop. From an international perspective, several herbicides (active ingredients) are registered for use in lentils worldwide, including cyanazine, glyphosate, imazethapyr, metribuzin, paraquat and trifluralin. Cool, wet conditions and abnormally hot temperatures at application time can induce a negative crop response. Herbicide-tolerant varieties, such as 'Clearfield'®, which carries a herbicide-tolerant trait, are available in Canada, allowing the use of imidazolinone herbicides that would otherwise cause injury to lentil varieties not carrying the trait.

Seed rate trial

The seed rate trial in 2022 showed a statistically significant differences ($p = 0.0011$) between the highest seed rate (300 viable kernels m^{-2} of 'Beluga noire') and the other seed rates (100, 150 and 200 kernels m^{-2}) resulting in a yield of 1047 kg ha^{-1} compared to yields of 616 kg (100 kernels), 815 kg (150 kernels) and 874 kg ha^{-1} (200 kernels) for the lower seed rates. This single year trial indicates a need to increase the minimum seed rate for Swedish conditions passed the recommendations for Alberta pulses (Anonymous 2023a) and Saskatchewan pulses (Anonymous 2023b). In Saskatchewan, the target density is 130 plants m^{-2}, and recommended seed rates range from 45 to 90 kg ha^{-1} depending on variety. Lentil plants appear to have a limited ability to compensate for low density. Optimum row spacing depends on lentil variety and cropping system. In narrow row spacings, the crop canopy closes faster, reducing the loss of water through soil evaporation. However, it is the combination of plant density used with a particular row spacing that determines the performance of the crop in a particular environment.

A low seed rate will generally result in a low competitiveness between crops and weeds. As the field trials in 2022 were affected by insufficient weed control, the low overall yields reflect both the influence of weed competition and the seed rates *per se*. In a weed free trial, yields of the four seeds rates may have been more similar. The seed rate trial included one variety only, the 'Beluga noire'. Other varieties may have a better ability to compete with weeds due to differences in emergence time, growth development, crop height and biomass of canopy. Further trials on seed rates with 4–5 varieties in weed free plots and plots with weeds should be carried out to improve the advice given to farmers for cropping.

Overall, the field trials clearly showed a need for effective weed control, either through herbicides or physical methods. The two pilot trials on herbicides give valuable knowledge on possible treatments, but further testing is needed regarding weed control effect, treatment times and doses.

Conclusions and recommendations

Lentils can be cropped in Sweden. However, cultivar choice and the ability to control annual weeds will have a major influence on yield and, thus, on economic success for the farmer. Yields can reach 3–4 MT ha^{-1} but are more likely to vary around 1.5–2.5 MT ha^{-1}.

We have neither studied fertilising strategies nor the influence of soil type on crop development and yield. The test sites had clear differences in soil types: dry sandy soil in Öland, typical clay soil in Skåne, and a loamy sandy soil in Halland. Fertilising strategies should be adopted to soil nutrient status. The early recommendations from Arrhenius (1862) indicate that lentils will give an acceptable yield in dry, sandy soils. A good yield will, according to Arrhenius, only be possible on fertile, well-fertilised, loamy calcareous sandy soil. As we obtained high yields in the Skåne trial, this early recommendation seems to be valid from a soil perspective. Recent studies (Mukherjee et al. 2023) recommend a fertiliser dose of 20:40:40 kg N-P_2O_5-K_2O ha^{-1} as a basal dose upon seeding.

Regarding suitable varieties, 'Beluga noire' (black seed coat), 'Rosana' and Redberry' (reddish seed coat), and the French Green varieties (green, or mixed-green seed coat), such as 'Kermit' and 'Anicia', are all promising, giving quite similar yield levels. Climate chamber experiments have shown differences in germination ability between cultivars, with 'Greenland' and 'Gotland' being better adapted to low soil temperatures compared to, for example, 'Redberry' and 'Beluga noire'. We conclude that a soil temperature of 10–12°C is the minimum to achieve an emergence of 80–90% ten days after seeding. From a farmer's perspective, care should be taken to select varieties suitable for the Scandinavian climate in case early seeding is needed. Yields were overall higher in the province of Skåne than those obtained in Halland or Öland. This might be connected to the higher sum of growing degree days in 2022 in Skåne, indicating that lentils either should be seeded earlier or mostly in southern part of Sweden. Further trials on this matter should be initiated.

In our study, mixing lentils with wheat or oats to improve weed competition and/or avoid lodging has not shown a clear positive result on yield, although tendencies towards higher yield in stands mixed with oats were recorded in 2021. The highest yields have been obtained in pure stands with a sufficient use of herbicides. Based on our results, we cannot generally support the idea of using mixed stands to increase yield of lentils. However, mixed stands could be utilised for other intermediary benefits, for example, to reduce lodging, as this was only observed in pure stands.

Regarding seed rate, 300 viable kernels m^{-2} seems to be the minimum for Swedish conditions. In the case of intensive physical weed control or seeding in intercropped stands, we suggest that this seed rate is increased.

Successful weed control is crucial for large-scale commercial production in Sweden. At the time of writing (2023), the number of herbicides allowed in lentil production is limited, but there is a range of registered herbicides in Europe with good weed efficacy and minor impacts on crop stand.

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