Pielikumi

Konferences programma

PLENĀRSĒDE 25. februārī pl. 10:00

Uzruna. LF dekāne, asociētā profesore **Dace Siliņa**

Zaļais kurss pārejai uz klimata neitralitāti. Vides aizsardzības un reģionālās attīstības ministrijas Dabas aizsardzības departamenta direktore **Daiga Vilkaste**

ES KLP stratēģiskais plāns Latvijai – līdzsvarota ekonomisko, vides un sociālo mērķu īstenošana. Zemkopības ministrijas Valsts sekretāra vietniece **Pārsla Rigonda Krieviņa**

Augu veselības un aizsardzības loma lauksaimniecības attīstībā Zaļā kursa ietvaros. Eiropas un Vidusjūras augu aizsardzības organizācijas eks-ģenerāldirektors **Ringolds Arnītis**

Sabalansētas ēdināšanas un rupjās lopbarības kvalitātes ietekme uz emisijām no piena lopkopības. LLKC Lopkopības kompetenču centrs, nodaļas vadītāja, lopkopības konsultante **Silvija Dreijere**

Lauksaimniecības noteču monitoringa rezultātu mainības tendences. LLU VBF Vides un ūdenssaimniecības katedras profesors **Ainis Lagzdiņš**

Ilgtspējīga lauksaimniecība praksē. Lauksaimnieku organizāciju sadarbības padomes valdes loceklis, Latvijas Jauno zemnieku klubs **Kārlis Ruks**

Ilgtspējīga lauksaimniecība no studenta skatupunkta. LAB stipendiāte, LF 3. kursa studente **Amanda Bernharde**

Lauksaimniecības un meža zinātņu devums līdzsvarotas lauksaimniecības sekmēšanā. LLMZA prezidente, profesore **Baiba Rivža**

SEKCIJU SĒDES 25. februārī pl. 14:00

LAUKKOPĪBA

Toksīnus izraisošo sēņu sastopamība un sugu identificēšana auzu dīgstos un skarās. Feodorova-Fedotova L., Jakobija I., Moročko-Bičevska I.

Kviešu slimības atkarībā no augsnes apstrādes un priekšaugiem. Bankina B., Bimšteine G., Kaņeps J., Roga A., Neusa-Luca I., Darguža M., Fridmanis D.

Slāpekļa papildmēslojuma un slimību ierobežošanas ietekme uz ziemas kviešu ražu un kvalitāti. Gaile Z., Bankina B., Plūduma-Pauniņa I., Šterna L., Bimšteine G., Švarta A., Kaņeps J., Arhipova I., Šutka A.

Lauka pupu un sojas šķirņu izvērtējums, gumiņbaktēriju efektivitāte un galvenie faktori augstākas pākšaugu ražas iegūšanai. Klūga A., Alsiņa I., Dubova L., Lepse L., Zeipiņa S.

LAUKA PUPU UN SOJAS ŠĶIRŅU IZVĒRTĒJUMS, GUMIŅBAKTĒRIJU EFEKTIVITĀTE UN GALVENIE FAKTORI AUGSTĀKAS PĀKŠAUGU RAŽAS IEGŪŠANAI

EVALUATION OF FABA BEAN AND SOYA CULTIVARS, THE EFFECT OF RHIZOBIA AND THE MAIN FACTORS FOR OBTAINING HIGHER QUALITY LEGUME YIELD

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Kopsavilkums. Pākšaugi, tajā skaitā lauka pupas un soja, ir proteīniem bagāti augi, kas ieņem būtisku vietu gan cilvēku pārtikā, gan lopbarībā. Turklāt pākšaugu audzēšana tiek uzskatītu par nozīmīgu ilgtspējīgas lauksaimniecības nodrošināšanā. Pākšaugu audzēšanas palielināšanai Eiropā būtu neskaitāmi ieguvumi, tajā skaitā – varētu nodrošināt Eiropas Savienības pašpietiekamību olbaltumvielu apgādē, tiktu samazināta nepieciešamība pēc ķīmiskā slāpekļa mēslojuma, samazināti siltumnīcas efekta gāzu emisijas apjomi, tiktu novērsta lauksaimniecības augšņu degradācija, kā arī tiktu uzlabota bioloģiskā daudzveidība. Neskatoties uz šīm priekšrocībām, pākšaugu ražošanas apjomi ES vēljoprojām ir nepietiekamā līmenī. Tiek uzskatīts, ka daļējs risinājums šai problēmai varētu būt pākšaugu šķirņu selekcijas un lauksaimniecības prakses, kā arī lauksaimnieku zināšanu uzlabošana. Projekta "Augu olbaltumvielu ražošanas produktivitātes un ilgtspējības palielināšana Eiropā" (LegumeGap) trīs gadu laikā paredzēts identificēt lauka pupu un sojas šķirņu potenciālu, kā arī optimālo lauksaimniecības praksi, audzējot pākšaugus, izvērtējot faktorus, kas varētu samazināt ražas mainīgumu visas Eiropas Savienības līmenī. Šī mērķa sasniegšanai projektā tika apskatītas dažādas ar lauka pupām un soju saistītas pētniecības tēmas. Projekta otrajā gadā (2020. g.) tika apkopota informācija par Latvijā audzētajām lauka pupu un sojas šķirnēm. Šajā gadā tika salīdzinātas 7 dažādas lauka pupu un 5 sojas šķirnes. Sojas šķirnes, kas uzrādījušas augstāko ražību, bija 'Protina' un 'Sirelia'. Tika apkopota arī literatūrā pieejamā informācija par lauka pupu sēklu inokulācijas ietekmi uz ražu, kā arī tika veikts lauka izmēģinājums, kurā tika novērtēta šī inokulācijas efektivitāte. Rezultāti uzrādīja būtisku gumiņbaktēriju inokulācijas pozitīvu ietekmi uz lauka pupu lapu skaitu, kā arī uz ražu. Turklāt, tika identificēta inokulācijas un audzēšanas apstākļu ietekme uz lauka pupu hlorofila saturu lapās. Viens no projekta galvenajiem uzdevumiem, lai identificētu lauka pupu un sojas ražas ietekmējošos faktorus, bija lauksaimnieku aptaujas uzsākšana, kuras mērķis ir noskaidrot lauksaimnieku pieredzi audzējot pākšaugus un identificēt būtiskākos faktorus, kas ietekmē pākšaugu ražu. Aptaujas provizoriskie rezultāti norāda, ka pēc lauksaimnieku domām, galvenie faktori, kas ietekmē ražu ir sējas laiks, dziļums un izsējas norma, kaitēkļu un nezāļu apkarošanas efektivitāte, kā arī sojas gadījumā – gumiņbaktēriju preparāta izmantošana. Projektu "Augu olbaltumvielu ražošanas produktivitātes un ilgtspējības palielināšana Eiropā" finansē LR Zemkopības ministrija atbilstoši MK noteikumiem Nr. 59 "Valsts un Eiropas Savienības atbalsta piešķiršanas kārtība investīciju veicināšanai lauksaimniecībā".

Atslēgas vārdi: *Vicia faba, Glycine max, inokulācija, Rhizobia, gumiņbaktērijas.*

Elemental content of faba beans affected by rhizobia and mycorrhiza fungi

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Introduction

One of the most important elements in all living organisms is nitrogen. Earth's atmosphere is rich in nitrogen (78%), but plants are not able to use it directly. Rhizobium-legume symbiosis is one way to make atmospheric nitrogen available for plants. In addition, effective plant symbiosis with mycorrhizal fungi can improve the availability of other mineral elements, especially phosphorus. Legumes, belonging to the Leguminosae plant family, also called Fabaceae, are one of the most important plants used both for human consumption as well as for feed. In combination with cereals, legumes can provide all amino acids necessary for human nutrition. In addition to legume valuable chemical composition, they also have an important property - symbiotic fixation of atmospheric nitrogen. Legume seed inoculation before sowing with rhizobia is a long-established, research-based practice. The use of rhizobia when growing legumes, including faba beans, significantly reduces the necessity of chemical nitrogen fertilizer use in agriculture. Therefore, legume-rhizobia symbiosis nowadays is a part of a sustainable agriculture practice, increasing the fertility and the structure of the soil

Experimental

A field experiment was conducted in the Study and Research Farm 'Pēterlauki', Latvia University of Life Sciences and Technologies. Small-seeded faba bean (Vicia faba var. minor) cultivar 'Lielplatone', obtained from State Priekuli Plant Breeding Institute in Latvia, was used. The sowing rate was 45 seeds per m2, plot size was 9 x 2 m. The experiment was done in four replicates. Rhizobium leguminosarum strains RP023 and RV407, used for seed inoculation, were obtained from the Collection of the Institute of Soil and Plant Sciences, Latvia University of Life Sciences and Technologies. Faba bean seed inoculation was done prior to sowing. Unsterilized seeds were soaked in a rhizobia strain suspension (106 cells per 1 mL) for 30 minutes. Seeds were air-dried before sowing.

Plants for analysis were collected during the flowering stage (stem and leaves) and after harvest (seeds). Samples were air-dried and inductively coupled plasma mass spectrometry (ICP-MS) was used for the determination of elements. Closed vessel microwave-assisted acid digestion method using trace grade nitric acid (Fischer) and hydrogen peroxide (Merck) was applied for sample preparation. Total nitrogen and carbon content were determined with an element analyser (EuroVector EA3000).

Results

From the obtained results, it is known that the most significant change in element concentration occurred in the leaves of beans. After treatment of legumes with rhizobia, mycorrhiza, and both rhizobia and mycorrhiza, significant changes occurred in the content of Na, P, Fe, Al, N. In the case of bean seeds, a significant change was only observed in the content of Zn and N. The most significant increase of nitrogen content was observed when legumes were treated with mycorrhiza. Changes in the element concentrations in the soil were not affected by the treatment of faba bean seeds with rhizobia strains and mycorrhiza fungi. The content of elements in the soil after harvest remained the same as it was before the experiment. In Figure 1 it is shown that there are relatively high concentrations of Mg, Ca, Mn, Fe, Cu, and Zn, but these elements are not accumulated in legume plants in comparison to Na, P, and K.

All plants must somehow respond to the stress caused by the effects of salinity. This is important so the plants can maintain the ability for the functioning of the plant when there is not enough water available and when high amounts of sodium and chloride ions are present. Usually, legumes have low sodium content, which is a beneficial factor for their growth. Obtained results show that most of the sodium content is accumulated in the leaves (Fig. 2).

In the experimental field, the initial content of N in soil was low and maintained at about 1.6 mg kg-1. After treatment with rhizobia and mycorrhiza, an elevated N content in the leaves was observed (from 37 to 31 mg kg-1). The content of nitrogen in faba beans changed from 44 mg kg-1 to 46 mg kg-1 when rhizobia and a mixture of rhizobia and mycorrhiza were used. In the case of mycorrhiza, the content of nitrogen in faba beans raised up to 55 mg kg-1, indicating a positive nitrogen fixation process. A significant increase in nitrogen content has been also found in other studies, where an increase in nitrogen content up to 20% was observed (Franzini et al., 2010). Legume plants, due to the formation of nodules, have a greater demand for P, explaining the slight decrease of P in the studied seeds (from 2700 to 2300 mg kg-1). Other studies have shown that the effect of inoculation on phosphorus content in plants depends on the variety of faba beans used (Franzini et al., 2010).

There was no significant change observed in the Fe content in faba beans. However, there was a slight decrease of Fe content in the leaves (from 55 to 48 mg kg-1). In the case of seed inoculation with rhizobia, there was not a significant increase in Fe (from 55 to 58 mg kg-1). Similar results have been reported in other studies, showing that inoculation with rhizobia promotes the accumulation of iron in beans by up to 11% (Uyanöz et al., 2012).

Study shows that there is an insignificant increase of Zn in studied legumes (from 14 to 17 mg kg-1 in leaves and from 20 to 22 mg kg-1 in soybean leaves). Other studies report an increase of zinc content up to 15% in dry garden bean seeds (Uyanöz et al., 2012).

Our study shows that Al concentration in leaves decreases after inoculation of legumes with rhizobia and mycorrhiza (from 39 to 30 mg kg-1), Al content in faba beans was less than 0.5 mg kg-1.

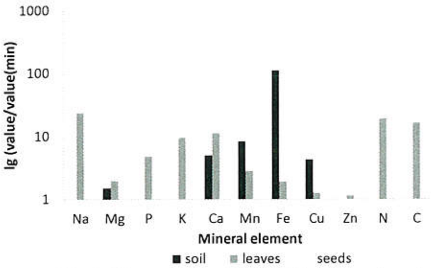

Fig. 1. Element content in soil, leaves, and seeds of faba beans.

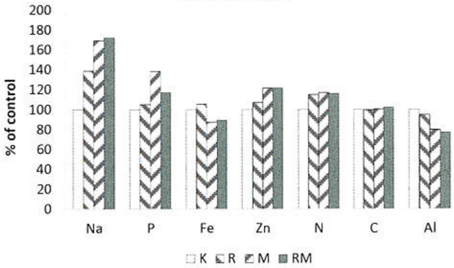

Fig. 2. Impact of different micro symbiotes on element content in faba bean leaves.

Conclusions

Obtained results show that inoculating legume plants with rhizobia, mycorrhiza, and both rhizobia and mycorrhiza not only changes nitrogen uptake by the plants but also changes the content of other elements. In this study, no matter which type of inoculant was used (rhizobia, mycorrhiza, or rhizobia and mycorrhiza), the increase in nitrogen content in faba bean leaves was up to 10%. Inoculation with mycorrhiza resulted in nitrogen increase in seeds up to 10%. Meanwhile, inoculation with only rhizobia or both rhizobia and mycorrhiza, resulted in a lower nitrogen increase - up to 5%. Faba bean seed treatment with different inoculants has a greater effect mainly on the element content of leaves, where a significant increase in Na, P, and Zn could be observed. Treatment of legume plants with rhizobia strains caused a decrease of Zn in seeds. In actively growing plant parts, the increase in Na and P content, as a result of inoculation with rhizobia, was observed at 70% and 40%, respectively. Different treatment techniques did not affect the content of Na and Al in seeds, which could be potentially toxic for plant functioning. The content of Na did not change in seeds while it was highly accumulated in leaves. Content of Al in seeds was very low and it even decreased in leaves after inoculation with rhizobia and mycorrhiza was applied.

Acknowledgments

The authors gratefully acknowledge the financial support of the EU 7th Research Framework Programme EUROLEGUME project (Enhancing of legumes growing in Europe through sustainable cropping for protein supply for food and feed), as well as SusCrop ERA-NET project LegumeGap, financed by the Ministry of Agriculture of the Republic of Latvia.

SĒJAS LAIKA IETEKME UZ LAUKA PUPU (*VICIA FABA* L.) RAŽU UN TĀS STRUKTŪRELEMENTIEM 2020. GADĀ

SOWING TIME EFFECT ON FIELD BEAN (VICIA FABA L.) YIELD AND ITS COMPONENTS IN 2020

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Kopsavilkums. Lauka pupas (*Vicia faba*) Latvijā tiek audzētas jau izsenis. Mūsdienās tām tiek pievērsta arvien lielāka uzmanība, izvēršot to pārstrādes iespējas ne tikai lopbarībai, bet arī pārtikai. Līdz šim Latvijā un Baltijā veikti salīdzinoši maz izmēģinājumu, kur pētīta vairāku faktoru ietekme uz lauka pupu ražas un tās struktūrelementu veidošanos. Šī pētījuma mērķis bija noskaidrot sējas laika ietekmi uz lauka pupu ražu un tās struktūrelementiem. Lauka izmēģinājums ierīkots Latvijas Lauksaimniecības universitātes mācību un pētījumu saimniecībā "Pēterlauki" 2020. gada veģetācijas sezonā. Tika pētīti četri faktori: A – sējas laiks (agrs (28.03.); vidēji agrs (07.04.); vēls (17.04.)); B – šķirne ('Laura', 'Boxer', 'Isabell'); C – izsējas norma (30, 40 un 50 dīgtspējīgas sēklas m^{-2}); D – fungicīda lietošana (F0 – bez apstrādes; F1 – apstrāde ar fungicīdu Signum (boskalīds, 267.0 g kg^{-1} un piraklostrobīns, 67.0 g kg^{-1}); apstrāde veikta 61.–65. AE, deva 1.0 kg ha^{-1}). Agrais sējas laiks izvēlēts kā visagrīnākais iespējamais 2020. g., bet pārējie – ar 10 dienu intervālu. Citi agrotehniskie pasākumi veikti saskaņā ar labas lauksaimniecības prakses nosacījumiem. Meteoroloģiskie apstākļi 2020. gada veģetācijas sezonā bija piemēroti augstu lauka pupu ražu ieguvei. Datu matemātiskai apstrādei izmantota dispersijas analīze programmā SPSS 15. Sējas laiks būtiski ietekmēja lauka pupu ražu ($p<0.0001$). Augstākā raža iegūta, sējot lauka pupas vidēji agrīnā sējas termiņā (6.95 t ha^{-1}), taču tā būtiski neatšķīrās no ražas, ko ieguva variantā, kuru sēja agrajā termiņā (6.77 t ha^{-1}) ($p=0.102$). Vēlajā sējas termiņā sētās pupas deva būtiski zemāku ražu (6.57 t ha^{-1}) ($p=0.014$). Atšķirībā no iepriekš veiktiem pētījumiem būtiski ($p<0.0001$) augstāka raža iegūta, lietojot šķirni 'Isabell' (6.96 t ha^{-1}). Tāpat vidēji augstāko ražu nodrošināja, sējot 40 un 50 dīgtspējīgas sēklas m^{-2} (atbilstoši 6.83 un 6.97 t ha^{-1}), kā arī, lietojot fungicīdu, iegūts būtisks ($p<0.0001$) vidējās ražas pieaugums + 0.47 t ha^{-1} (7.00 t ha^{-1}), kas izskaidrojams ar plašo pupu lapu slimību izplatību 2020. g. Sējas laiks 2020. g. būtiski ($p<0.0001$) ietekmēja produktīvo stublāju skaitu m^{-2} un 1000 sēklu masu ($p<0.0001$). Visvairāk produktīvo stublāju m^{-2} ražas novākšanas laikā konstatēts vēlajā sējas termiņā (42.5 gab.) sētajos lauciņos. Savukārt būtiski zemāks to skaits atzīmēts agrajā sējas termiņā (36.3 gab.) sētajos lauciņos. Savukārt 1000 sēklu masa būtiski visaugstākā bija tieši variantā, kad pupas sēja agrīnajā sējas termiņā. Sējas laikam nebija matemātiski būtiska ietekmes uz šādiem lauka pupu ražu veidojošiem struktūrelementiem: pākšu skaits augam ($p=0.307$), sēklu skaits pākstī ($p=0.367$) un sēklu skaits augam ($p=0.149$). Vislielāko pākšu skaitu augam nodrošināja sēja vidējā sējas termiņā (13.6 gab.), bet sēklu skaits augam (39.8 gab.) un sēklu skaits pākstī (2.98 gab.) vislielākais iegūts, sējot pupas vēlajā sējas termiņā. Šajā gadā sēklu skaits augam (43.2 gab.) un sēklu skaits pākstī (3.2 gab.) būtiski augstāks ($p<0.0001$) novērots šķirnei 'Isabell', kurai uzskaitīts arī vislielākais pākšu skaits augam (13.7 gab.), kas izskaidro šīs šķirnes būtiski augstāko vidējo ražu, kas, vērtējot sējas laikus atsevišķi, bija būtiski augstāka nekā abām pārējām šķirnēm tieši variantos, kas sēti vēlajā sējas termiņā. Lai arī augstāks sēklu skaits augam novērots variantos, kas sēti vēlajā sējas laikā, tās visas nespēja pilnvērtīgi nogatavoties, lai arī šī gada vēlais sējas laiks nebija izteikti vēlīns (17.04.). Lai arī atsevišķi ražas struktūrelementi augstākās vērtības uzrādīja variantos, kas sēti vēlajā sējas laikā, tomēr, vērtējot 2020. gadā iegūto ražu, jāsecina, ka šajā gadā vidēji agrais un agrais sējas laiks bija vispiemērotākie augstas lauka pupu ražas ieguvei.
Pētījumu atbalsta projekts LegumeGap (Augu olbaltumvielu ražošanas produktivitātes un ilgtspējības palielināšana Eiropā), kā arī LLU MPS "Pēterlauki".
Atslēgas vārdi: *lopbarības pupas, šķirne, izsējas norma, fungicīda lietošana.*

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Sowing time effect on yield and quality of field beans in a changing meteorological situation in the Baltic region

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Abstract. As field beans (*Vicia faba* L.) need a lot of moisture to germinate, growers believe that they should be sown as early as possible in the spring. Field trial was carried out at the LLU RSF "Pēterlauki", from 2018 to 2020. Following factors were researched: A) sowing time (early, medium and late), B) variety ('Laura', 'Boxer', 'Isabell'), C) sowing rate (30, 40, 50 germinable seeds m^{-2}), D) fungicide application (without and with application of fungicide at the GS 61-65). Meteorological conditions during the study had the greatest impact on the results as they were contrasting. Adverse meteorological conditions for field bean growing were observed in 2018 and in spring and early summer of 2019. The best year for bean yield formation was 2020, when temperature and precipitation was moderate. The highest average three year been yield was obtained sowing beans at the medium sowing time, however, equivalent yield was obtained sowing beans also in early sowing time. Fungicide application increased average three year yield significantly ($p = 0.007$) and independently of the sowing time. Influence of variety and sowing rate on average three year yield was insignificant, and it was not proved that any variety or sowing rate could be more suitable in a specific sowing time. Average three-year values of crude protein content, thousand seed weight and volume weight were affected by sowing time significantly ($p < 0.001$). Trial year, variety and fungicide application also affected all quality parameters significantly ($p < 0.05$), but the effect of sowing rate was insignificant ($p > 0.05$).

Key words: *Vicia faba* spp. *minor*, sowing time, variety, sowing rate, fungicide application.

INTRODUCTION

Field beans (*Vicia faba* L.) are well known all over the world. Mostly they are used for food and feed consumption. Although field bean sowing area has not considerably changed overall the world for more than thirty years (around 2.5 million ha each year[1]), in Baltic countries the sowing area has significantly grown during the last decade. Last decade showed not only a significant increase in sowing area, but also an increase of

[1] FAOstat data base: http://www.fao.org/faostat/en/#data/QC.

bean seed yield (from 0.27 t ha^{-1} in Estonia, 2012; up to 3.68 t ha^{-1} in Latvia, 2017)[2]. The same tendency is observed in the European and world data. It could mean that farmers are interested to make beans' growing more profitable, adjusting agrotechnical measures for obtaining higher seed yields. This presumption was confirmed by a farmers' survey conducted within the framework of SusCrop - ERA-NET project LegumeGap 'Increasing productivity and sustainability of European plant protein production by closing the grain legume yield gap'. In Latvia, farmers mentioned the following as the most important factors influencing field beans yield: sowing time, depth and rate, pest control measures; as important factors also variety choice, as well as interval before re-cultivation of field beans in the same field were mentioned (Klūga, 5 November 2020, oral report in scientific seminar, held by Faculty of Agriculture of LLU).

Growers in Baltic region, specifically in Latvia, believe, that higher field bean seed yield could be obtained by sowing beans in the earliest possible timing, which is connected with beans' high water demands and tolerance to comparatively low temperature during germination. High seed yields (5.8–7.3 t ha^{-1}) were obtained sowing beans in late March or first decade of April in previous our researches carried out in Latvia (Plūduma-Pauniņa et al., 2018), but at the same time germination of the beans (from GS 00 until GS 11) took from 36 to 44 days depending on the trial year (Plūduma-Pauniņa et al., 2019). In contrast, sowing time of the beans often occurs in the last decade of April or even in early May in the production conditions, despite the opinion that beans must be sown as early as possible. For instance, beans' demonstration trial was sown in the third decade of April, and obtained seed yield varied from 2.9 to 3.3 t ha^{-1} (Mellere, 2016), but another production occasion tells about field beans' sowing in the first decade of May, and the obtained seed yield in this case was 3.8 t ha^{-1} (Bartuševics, 2014).

Several researches have been carried out all over the world about sowing time effect on field bean yield and quality in diverse climatic conditions. Most of the research results gave evidence that earlier sowing time of beans ensures higher yield, if compared to sowing them in late sowing timing (Loss & Siddique, 1997; Tawaha & Turk, 2001; Hassan, 2008; Ibrahim et al., 2009; French, 2010; Badr et al., 2013; Alharbi et al., 2015; Raymond et al., 2016). However, some research results gave the opposite conclusion (e.g., Landry et al., 2016) about sowing time effect on seed yield.

Most of the above mentioned researches about field beans have been carried out in Australia, USA or in the Middle East (Egypt, Iran, Jordan, and Turkey). Unfortunately, it was not possible to find any recently published scientific results obtained in the Baltic region on field beans' sowing time and its interaction with other agro-technical elements such as variety, sowing rate and fungicide application for disease control.

Our research was aimed to clarify the influence of sowing time together with other agrotechnological factors on field bean yield and quality in the changing meteorological conditions.

MATERIALS AND METHODS

Research was carried out in three-year period: from 2018 to 2020. Field trials were performed at the Research and Study Farm "Pēterlauki" (56°32'31.2"N 23°42'57.6"E) of the Latvia University of Life Sciences and Technologies. Four factors were researched

[2] EUROstat data base: https://ec.europa.eu/eurostat/data/database.

each year: factor A - sowing time (early, medium and late, Table 1); factor B - variety ('Laura', 'Boxer', 'Isabell'); factor C - sowing rate (30, 40 and 50 germinable seeds per 1 m^2); factor D - fungicide application (without fungicide and with fungicide Signum (boscalid, 267.0 g kg^{-1}, pyraclostrobin, 67.0 g kg^{-1}) application at the GS 61-65). Each year 54 variants in 4 replications were sown. In the data mathematical processing trial year was considered as the fifth factor because of the annual meteorological conditions' differences. Plot size was 16 m^2 (1.6 × 10 m).

Each year the early sowing was performed on the earliest possible date, which depended on meteorological conditions; and around 10 day interval was maintained between sowing timings (Table 1).

Table 1. Field bean sowing dates in all three trial years, Pēterlauki, Latvia

Sowing time	Trial year 2018	2019	2020
Early	21 April	05 April	28 March
Medium	29 April	15 April	07 April
Late	08 May	25 April	17 April

In the field trial, varieties were chosen based on their popularity between farmers in Zemgale region of Latvia; they are also widely used in all Baltic countries and Northern Europe. Varieties 'Laura' and 'Boxer' are well known for their high productivity, but variety 'Isabell' - for high crude protein content in seeds. Another reason of variety preference was the use of the same varieties in our previous research (Plūduma-Pauniņa et al., 2018, 2019).

The soil at the trial site was silt loam, Endocalcaric Abruptic Luvisol (World Reference Base, 2014). Depending on each year trial location site, soil agrochemical indices was as follows: pH_{KCl} - 6.5–6.9; organic matter (%) - 3.0–3.5; P_2O_5 (mg kg^{-1}) - 104–181; K_2O (mg kg^{-1}) - 150–207. Traditional soil tillage was used - ploughing in the autumn and soil cultivation before each sowing time. Fertilizing and spraying of plant protection products performed as needed, according to the rules of good agricultural practice (Table 2). Fungicide Signum (dose 1.0 kg ha^{-1}) was used based on the trial scheme at GS 61-65 (flowering).

Table 2. Used agro-technology in field beans' trial, 2018–2020, Pēterlauki, Latvia

Agro-technology	Trial year 2018	2019	2020
Fertilizer NPK 15-15-15 + 11 S (BS), kg ha^{-1}	250	200	250
	37.5	30.0	37.5
	37.5	30.0	37.5
	37.5	30.0	37.5
Foliar fertilizers			
YaraVita™ Brassitrel Pro, L ha^{-1}	1.0	2.0 + 1.0	–
Boron, L ha^{-1}	1.0	2.0 + 1.0	–
Herbicides			
Pendimethalin (330 g L^{-1}) (GS 07), L ha^{-1}	2.0	2.0	2.0
Bendioxide (480 g L^{-1}) (GS 14), L ha^{-1}	–	2.0	2.0
Cycloxydim (100 g L^{-1}) (GS 39), L ha^{-1}	1.0	2.0	–
Quizalofop-P-etil (50 g L^{-1}) (GS 30), L ha^{-1}	–	–	1.2
Insecticides			
Alpha–cypermethrin (50 g L^{-1}) (GS 61), L ha^{-1}	–	0.25	–
Thiacloprid (100 g L^{-1}), deltamethrin (10 g L^{-1}) (GS 61-65), L ha^{-1}	0.75	0.75	–

Notes: BS – before sowing; foliar fertilizers were given together with insecticides (in 2019 also with herbicide; GS 39) at the start of flowering (GS 61-65).

During vegetation, main phenological phases were observed, but severity of diseases was noted each week after emerging of the first symptoms (both are not analysed in detail in this paper).

Yield was harvested (Table 3) from each plot by small trial combine (Sampo 130) at the GS 89, weighted and recalculated to the standard moisture (14%) and 100% purity. Seed samples were taken for quality analysis from each plot's yield. Only crude protein (CP) content (% on dry matter basis) in seeds was detected using analyser Infratec™ NOVA (FOSS), but seed volume weight (VW) (g L^{-1}) (LVS EN ISO 7971-3: 2011) and thousand seed weight (TSW) (g) (LVS EN ISO 520: 2011) was detected according to the standard methods.

Table 3. Field beans' harvest dates, Pēterlauki, Latvia, 2018–2020

Sowing time	Trial year 2018	2019	2020
Early	13 August	29 August	04 Septemb
Medium	13 August	29 August	04 Septemb
Late	04 September	05 September	04 Septemb

April of 2018 was characterised with high average air temperatures and lot of precipitation (Table 4). High soil moisture delayed field bean sowing significantly (Table 1). In general, the season was atypically dry and hot (Table 4), thus resulting with low field beans' yields.

Table 4. Meteorological conditions during research period in Pēterlauki, Latvia, 2018–2020

Month	Average air temperature, °C				Precipitation, mm			
	2018	2019	2020	Norm	2018	2019	2020	Norm
March	-2.0	3.0	3.1	-1.5	10.8	29.6	27.0	31.3
April	9.0	8.1	6.1	5.3	69.5	3.0	9.2	40.0
May	16.1	12.4	9.9	11.7	12.0	57.0	30.0	51.4
June	16.8	19.4	18.7	15.4	16.0	32.0	140.0	75.3
July	20.7	16.8	17.0	16.6	56.5	93.5	48.0	81.7
August	19.4	17.6	17.7	16.2	34.0	37.8	65.0	73.7
September	14.9	12.7	14.9	11.5	25.4	53.6	24.0	62.7
Per season	13.6	12.9	12.5	10.7	Σ224.2	Σ306.5	Σ343.2	Σ416.1

Note: Norm means long-term average observations.

April 2019 started with almost no precipitation. Average air temperature was lower than that in previous year during the same date. In May, average air temperature was optimal, and the amount of precipitation sufficient, but June was hot and with lack of moisture. Stabilization of meteorological conditions for field bean growing in July could not recover the development delay at the beginning of growing season fully. In 2020, average air temperature at the end of March (1.6 °C on average per lasts ten-day period), April and May (Table 4) was lower than that in the previous two trial years. At the same time, moisture conditions were suitable for soil tillage and early field beans' sowing. June and the rest of the vegetation period was warmer, and with high precipitation amount, thus it was enough to develop high field beans' yield.

The General Linear Model Univariate Procedure was used for analysis of variance for factorial design using SPSS 15 software. For the comparison of factors' means Bonferroni test was used. Variants are considered significantly different when $p \leq 0.05$.

As a significant effect of year conditions was observed on the studied parameters during the trial period (Table 5), results of each year were analysed also separately.

RESULTS AND DISCUSSION

The average per trial year **field beans' yield** was 2.49 t ha^{-1} in 2018; 6.32 t ha^{-1} in 2019, and 6.75 t ha^{-1} in 2020. Conditions of the trial year had the greatest impact on average field beans' yield and its quality ($p < 0.0001$) according to the test of between subjects' effect (Table 5). The factor with the next largest effect on the studied parameters was the sowing time ($p < 0.0001$). Used field bean variety did not affect the average seed yield significantly ($p = 0.9$), but a significant effect of it was observed on crude protein (CP) content in seeds, volume weight (VW) and thousand seed weight (TSW) ($p < 0.0001$). Sowing rate did not affect neither average seed yield ($p = 0.123$), nor any of the previously mentioned quality indicators (respectively: $p = 0.725$, $p = 0.827$, $p = 0.817$) significantly.

Table 5. Type III Sum of squares for researched factors per whole trial period, 2018–2020

Researched factors	Researched results			
	Yield	CP content	VW	TSW
Trial year*	2373.099	70.036	169848.476	1570370.313
Sowing time	139.680	26.832	23575.525	160470.451
Variety	0.908	55.665	17020.012	85460.588
Sowing rate	18.045	0.749	213.718	1599.551
Fungicide application	31.142	5.593	6830.776	175668.786

*– conditions in trial year; CP – crude protein, VW – volume weight, TSW – 1,000 seed weight.

Fungicide application (Table 5) had a significant impact on seed yield ($p = 0.007$), as well as on CP content in seeds ($p = 0.028$), VW and TSW ($p < 0.0001$). Four field beans' diseases, which needed to be controlled, were observed in the trial every year (more detailed information is given by Bankina et al., 2021). Chocolate spot (caused by *Botrytis* spp.) and *Alternaria* leaf blight (caused by *Alternaria* spp. and *Stemphylium* spp.) were the most important field beans' leaf diseases. Rust (caused by *Uromyces viciae-fabae*) and downy mildew (caused by *Peronospora viciae*) did not reach a significant level. The highest severity of leaf diseases was observed in 2020 for both main leaf diseases, but the lowest - in 2019. Early sowing time essentially promoted the development of both diseases. Fungicide application decreased severity of both diseases significantly, and in result improved yield and quality of field beans.

As the conditions of the trial year had the most significant impact on the results, the yield of each year and its quality will be analysed separately.

In 2018, the field beans' yield was the lowest per trial period regardless of the beans' sowing time (0.94–3.21 t ha^{-1}, Table 6), due to hot and dry weather that had rarely been observed for the last 100 years[3]. The average field beans' seed yield was significantly affected only by sowing time ($p < 0.0001$) and fungicide application

[3] Latvian Environment, Geology and Meteorology Centre. https://www.meteo.lv/lapas/laika-apstakli/klimatiska-informacija/laika-apstaklu-raksturojums/2018/gads/2018-gads-sausakais-noverojumu-vesture?id=2374&nid=1177 [in latvian].

($p = 0.014$) (Table 6). The effect of variety ($p = 0.236$) and sowing rate ($p = 0.299$) on average seed yield was insignificant. Sowing time had the biggest impact on the average field beans' seed yield, and the highest yield was obtained when beans were sown in medium sowing time (3.33 t ha^{-1}), but it did not differ significantly from that obtained when sowing crop in early sowing time (3.21 t ha^{-1}) ($p = 0.214$). Yield obtained from variants sown in late sowing time was significantly lower (Table 6), and the yield decrease, if compared to the variants sown in the early and medium timings, was 2.27 t ha^{-1} (by 71%) and 2.39 t ha^{-1} (by 72%), respectively. Application of fungicide gave average yield increase by 0.39 t ha^{-1}. This tendency was noted for variants sown in all sowing times; the biggest yield increase by fungicide application was obtained when beans were sown in medium sowing time (+ 0.57 t ha^{-1}) ($p < 0.0001$).

Table 6. Field beans' yield (t ha^{-1}) depending on researched factors in 2018, Pēterlauki, Latvia

Factor	Sowing time ($p < 0.0001$)			Average
	early	medium	late	
Variety ($p = 0.236$)				
Laura	3.27^{a}	3.38^{a}	0.92^{ab}	2.52^{A}
Boxer	3.38^{a}	3.48^{a}	1.06^{a}	2.64^{A}
Isabell	2.97^{b}	3.13^{a}	0.83^{b}	2.31^{A}
Sowing rate (germinable seeds m^{-2}) ($p = 0.299$)				
30	2.98^{b}	3.12^{b}	0.90^{a}	2.33^{A}
40	3.22^{ab}	3.36^{ab}	0.93^{a}	2.50^{A}
50	3.42^{a}	3.52^{a}	0.97^{a}	2.64^{A}
Fungicide application ($p = 0.014$)				
F0	3.00^{b}	3.05^{b}	0.85^{b}	2.30^{B}
F1	3.42^{a}	3.62^{a}	1.02^{a}	2.69^{A}
Average	3.21^{A}	3.33^{A}	0.94^{B}	×

F0 – without fungicide application; F1 – with fungicide application.

Significantly different means are labelled with different letters in superscript: A, B – significant difference for average yields of three sowing times and means of factors' gradations; a, b – significant difference in a specific sowing time.

The second trial year (2019) was characterised with slightly better meteorological conditions for field beans' growth and development. Although the start of vegetation was cooler and some drought was observed, later conditions improved (Table 4), and field beans could form high yield (Table 7). The field beans' yield was significantly affected by three of four investigated factors except variety ($p = 0.113$), and the variety effect on seed yield was insignificant regardless of the sowing time ($p = 0.191$; $p = 0.798$; $p = 0.373$, respectively) (Table 7). The significantly highest field beans' seed yield was provided sowing beans in medium sowing time (6.54 t ha^{-1}) ($p < 0.0001$). Lower and similar seed yields ($p = 0.543$) were obtained sowing beans in early and late sowing timings. It could be explained with

Table 7. Field beans' yield (t ha^{-1}) depending on researched factors in 2019, Pēterlauki, Latvia

Factors	Sowing time ($p < 0.0001$)			Average
	early	medium	late	
Variety ($p = 0.113$)				
Laura	6.34^{a}	6.56^{a}	6.23^{a}	6.38^{A}
Boxer	6.32^{a}	6.59^{a}	6.20^{a}	6.37^{A}
Isabell	6.14^{a}	6.48^{a}	6.22^{a}	6.22^{A}
Sowing rate (germinable seeds m^{-2}) ($p < 0.0001$)				
30	6.13^{a}	6.32^{b}	5.85^{b}	6.10^{B}
40	6.29^{a}	6.51^{ab}	6.24^{a}	6.35^{A}
50	6.38^{a}	6.80^{a}	6.38^{a}	6.52^{A}
Fungicide application ($p < 0.0001$)				
F0	6.19^{a}	6.20^{b}	5.86^{b}	6.08^{B}
F1	6.34^{a}	6.89^{a}	6.46^{a}	6.56^{A}
Average	6.27^{B}	6.54^{A}	6.16^{B}	×

F0 – without fungicide application; F1 – with fungicide application.

Significantly different means are labelled with different letters in superscript: A, B – significant difference for average yields of three sowing times and means of factors' gradations; a, b – significant difference in a specific sowing time.

meteorological conditions in June - when beans sown in early sowing time started to flower, air temperature was high, but precipitation amount was low, therefore beans produced less flowers and later - pods.

These conditions did not cause stress for beans sown in late sowing time as their flowering started two weeks later when conditions improved. Only a small decrease in beans' yield was observed in this study year when beans were sown in early and late sowing timings, if compared with the variants sown in the medium sowing time (by 4% and 6%, respectively).

In 2019, detailed analysis of sowing rate effect on beans' seed yield showed that it differed depending on sowing timing. The highest yield always was obtained sowing 50 germinable seeds m^{-2}, but this yield did not differ significantly from any other sowing rate variant in early sowing time and from variant where 40 germinable m^{-2} seeds were sown in medium and late sowing timings (Table 7).

The average seed yield was affected also by fungicide application ($p < 0.0001$), like in 2018. In medium and late sowing time yield increase by fungicide application was significant ($p < 0.0001$). On average, fungicide application gave 0.48 t ha^{-1} (by 8%) seed yield increase.

The third trial year (2020) can be characterized as the best for field beans' yield formation according to meteorological conditions despite cold April. In 2020, the average yield was significantly affected by all four researched factors ($p < 0.0001$) (Table 8). The medium sowing time showed the best results for field beans' yield (6.95 t ha^{-1}) formation, but similarly to 2018, average yield obtained in variant sown in this sowing time did not differ significantly ($p = 0.102$) from that harvested in early sown variant (Table 8). Decrease of yield sowing beans in late sowing timing was 0.38 t ha^{-1} (by 5.5%), if compared with the variant sown in the medium timing, and 0.20 t ha^{-1} (by 3%), if compared with the variant sown in the early timing.

In 2020, the variety 'Isabell' provided the significantly ($p < 0.05$) highest average yield (Table 8) in contrast not only to previous trial years of current research, but also in contrast to our previously published results (Plūduma-Pauniņa et al., 2018). The variety effect on beans' yield was more expressed in medium and late sowing timings (Table 8). The sowing rate showed a significant impact on field beans' yield. The highest yield was observed mostly when the highest sowing rate (50 germinable seeds m^{-2}) was used (Table 8), and this effect was

Table 8. Field beans' yield (t ha^{-1}) depending on researched factors in 2020, Pēterlauki, Latvia

Factors	Sowing time ($p < 0.0001$)			Average
	early	medium	late	
Variety ($p < 0.0001$)				
Laura	6.65^{a}	6.71^{b}	6.48^{b}	6.61^{B}
Boxer	6.81^{a}	6.92^{ab}	6.41^{b}	6.71^{B}
Isabell	6.85^{a}	7.21^{a}	6.83^{a}	6.96^{A}
Sowing rate (germinable seeds m^{-2}) ($p < 0.0001$)				
30	6.44^{b}	6.69^{b}	6.34^{b}	6.49^{B}
40	6.90^{a}	7.07^{a}	6.52^{b}	6.83^{A}
50	6.96^{a}	7.07^{a}	6.86^{a}	6.97^{A}
Fungicide application ($p < 0.0001$)				
F0	6.55^{b}	6.69^{b}	6.34^{b}	6.53^{B}
F1	6.99^{a}	7.20^{a}	6.81^{a}	7.00^{A}
Average	6.77^{A}	6.95^{A}	6.57^{B}	×

F0 – without fungicide application; F1 – with fungicide application.

Significantly different means are labelled with different letters in superscript: A, B – significant difference for average yields of three sowing times and means of factors' gradations; a, b – significant difference in a specific sowing time.

significant in variants sown late. On average, the yield did not differ significantly between sowing rate variants 50 and 40 germinable seeds m^{-2} similarly to results obtained in 2019, and to our previously obtained results (Plūduma-Pauniņa et al., 2018). In 2020, fungicide application has increased field beans' average seed yield significantly ($p < 0.0001$) in similar amount (by 0.47 t ha^{-1}) as in previous years.

Bonelli et al. (2016) concluded that the choice of a suitable sowing time could minimize impact of some biotic and abiotic factors on plant phenological development. A significant effect of sowing time on plant growth and development together with the yield can be observed especially in field beans. Our results showed that early and medium sowing timing can provide similar bean yields. In Australia, in absolutely different conditions, if compared to those in Baltic region, a two-year trial in two locations with two different varieties and three sowing times was carried out, and Manning et al. (2020) concluded that regardless of the variety used, the trial year and location, the significantly highest field beans' yield was obtained in medium sowing time (3.05 t ha^{-1}). Similarly to our results, a decrease of field beans' seed yield with later sowing times was found also in other researches (Turk & Tawaha, 2002; Badr et al., 2013; Alharbi et al., 2015; Raymond, 2016; Wakweya et al., 2016; Zeleke & Nendel, 2019).

A significant impact of other researched factors on the field beans' yield was found in some previous researches carried out in Latvia. For example, in our previous work (Plūduma-Pauniņa et al., 2018), the variety 'Boxer' provided the significantly highest yield on average in two from three trial years. In other trials carried out in Latvia, the yield depended on the trial site, and varieties 'Laura' and 'Isabell' gave the highest yield in different sites (Zute, 2014). Our current research showed good results of all three mentioned varieties, which were not dependent from the sowing time, but rather from the conditions of the trial year in general. Sowing rate increase positively impacted field beans' yield. Our current results and previous work (Plūduma-Pauniņa et al., 2018) showed that yield was higher when 40 and 50 germinable seeds m^{-2} were sown, but evidence that different sowing rates are needed in different sowing timings was not obtained. Similarly, researches showed a diverse impact of sowing rate on beans' seed yield in different climatic condition. Loss et al. (1998) found in three-year trial that the increase of field beans' sowing rate increases the obtained yield. But it does not happen indefinitely - there is an optimum sowing rate, and, in their trial, it was 45 germinable seeds m^{-2}, which differed significantly from previously recommended sowing rate in Australia - 30 germinable seeds m^{-2} (Loss et al., 1998). Lopez-Bellido et al. (2005) also concluded that there is a maximum point up to which we can increase sowing rate for obtaining a higher yield. Research results in Mediterranean conditions showed completely opposite results - higher field beans' yield was obtained using lower seeding rate (larger row spacing) (Thalji, 2006; Yucel, 2013b). Kikuzawa (1999), and Yucel (2013a) found that too high sowing rate can decrease field beans' yield, which is based on the self-regulation of plant density.

Significant field bean yield increase using fungicide was obtained regardless of the sowing timing variant. Chemical control methods of the field beans' diseases can increase seed yield, when used in the right time, according to the rules of good agricultural practice (Stoddard et al., 2010; Kora et al, 2016; Plūduma-Pauniņa et al., 2018).

Crude protein (CP) content in seeds was affected by the trial year (Table 5), but observed fluctuation was within 1% (30.96% (2019) - 31.67% (2018)). On average per all three trial year's, the highest CP content in seeds was obtained when beans were sown in late sowing time (31.61%), and it was slightly (by 0.47%) higher, if compared with the lowest result obtained on average in plots sown in early sowing time. Similarly, the average CP content fluctuation depending on variety was within 1% (the highest CP content was provided by the variety 'Isabell' (31.81%), but the lowest - by the variety 'Boxer' (31.10%). Sowing rate did not give a significant effect on average three year CP content, but fungicide application gave a slight decrease of it (by 0.18%).

CP content in **2018** was significantly affected only by sowing time and field beans' variety (Table 9). On average, the highest ($p < 0.0001$) CP content in seeds was obtained using the variety 'Isabell' (32.26%). The same tendency was obtained sowing beans in early and medium sowing times, but the variety 'Laura' (32.39%) showed the insignificantly ($p = 0.428$) highest CP content when sown in the late sowing time. The highest CP content in seeds was observed sowing field beans in late and medium sowing times (Table 9).

In the **second trial year (2019)**, CP content in seeds was affected only by variety and fungicide application. In 2019, the impact of sowing time on CP content in seeds was insignificant ($p = 0.561$). Similarly to results in 2018, the highest CP content in seeds was noted if beans were sown in the late sowing time, but it was only slightly higher, if compared with that when beans were sown in the early sowing time.

Variation of CP content in seeds depending on variety was similar to that observed in the first trial year (Table 9). Fungicide application affected the CP content in seeds negatively, i.e., caused CP decrease in beans' seeds in all the variants; when beans were sown in early and medium sowing times this decrease was insignificant ($p = 0.174$; $p = 0.471$, respectively); in variants sown in late sowing time - even though the decrease was small (by 0.45%), it was mathematically significant ($p = 0.003$).

Table 9. Crude Protein content (%) in field beans' seeds depending on researched factors, 2018–2020

Factors	Year and sowing time								
	2018 ($p < 0.0001$)			2019 ($p = 0.561$)			2020 ($p = 0.850$)		
	early	med*	late	early	med	late	early	med	late
Variety ($p_{2018} = 0.0001$; $p_{2019} < 0.0001$; $p_{2020} < 0.0001$)									
Laura	30.57^{b}	31.63^{b}	32.39^{a}	31.08^{a}	31.06^{a}	30.97^{ab}	31.52^{ab}	31.34^{b}	31.64^{a}
Boxer	30.22^{b}	31.56^{b}	31.89^{a}	30.60^{b}	30.54^{b}	30.77^{b}	31.40^{b}	31.38^{b}	31.56^{a}
Isabell	31.83^{a}	32.88^{a}	32.07^{a}	31.04^{a}	31.25^{a}	31.31^{a}	32.00^{a}	32.08^{a}	31.85^{a}
Sowing rate (germinable seeds m^{-2}) ($p_{2018} = 0.858$; $p_{2019} = 0.570$; $p_{2020} = 0.945$)									
30	30.81^{a}	31.92^{a}	32.06^{a}	30.93^{a}	30.89^{a}	30.91^{a}	31.83^{a}	31.50^{a}	31.61^{a}
40	31.26^{a}	32.08^{a}	31.83^{a}	30.89^{a}	31.10^{a}	31.06^{a}	31.61^{a}	31.61^{a}	31.75^{a}
50	30.54^{a}	32.06^{a}	32.46^{a}	30.90^{a}	30.86^{a}	31.07^{a}	31.47^{a}	31.69^{a}	31.68^{a}
Fungicide application ($p_{2018} = 0.160$; $p_{2019} = 0.037$; $p_{2020} = 0.347$)									
F0	31.09^{a}	32.06^{a}	32.27^{a}	30.99^{a}	30.90^{a}	31.24^{a}	31.86^{a}	31.64^{a}	31.59^{a}
F1	30.65^{a}	31.98^{a}	31.96^{a}	30.82^{a}	31.00^{a}	30.79^{b}	31.42^{b}	31.56^{a}	31.78^{a}
Average	30.87^{B}	32.02^{A}	32.12^{A}	30.91^{A}	30.95^{A}	31.02^{A}	31.64^{A}	31.60^{A}	31.68^{A}

*med – medium; F0 – without fungicide application; F1 – with fungicide application.

Significantly different means are labelled with different letters in superscript: A, B – significant difference for average yields of three sowing times in a specific year; a, b – significant difference in a specific sowing time.

In the **third trial year (2020),** CP content in seeds was significantly affected only by one researched factor - the variety ($p < 0.0001$), and the highest CP content regardless of the sowing time was provided by the variety 'Isabell' (Table 9).

Kondra (1975) concluded that, although sowing date did not affect CP content in seeds significantly, the tendency was to decrease CP content within later sowing dates (from 29.2% to 26.9%). It is in contrast with the tendency we have observed, whereas, Rowland (1978) concluded that CP fluctuation among sowing timing variants is rather random. In currently described research, the impact of sowing rate on CP content was insignificant. It is in contrast with our previous research results (Plūduma-Pauniņa et al., 2018), when we found that CP content in seeds tended to be higher when higher sowing rate was used. The same tendency was observed also in trial carried out in Egypt (Bakry et al., 2011). The effect of variety on CP content is similar to our previous results (Plūduma-Pauniņa et al., 2018), and mainly 'Isabell' provided the highest CP content in seeds. Fungicide application showed decreasing effect on CP content, that is in contrast with the previously obtained results (Micek et al., 2015; Plūduma-Pauniņa et al., 2018). As CP content fluctuation was within 1%, this variation could be explained by interaction of researched factors with meteorological conditions in every specific study.

The volume weight (VW) on average was significantly ($p < 0.0001$) affected by the trial year (736 g L^{-1} (2020) - 774 g L^{-1} (2019); Table 5). On average per all three trial year's, the highest VW was obtained sowing field beans in early sowing time (763 g L^{-1}), and VW decreased in variants of every next sowing time (medium sowing time - 761 g L^{-1}, late sowing time - 750 g L^{-1}). A significant effect on average VW was showed also by the variety ($p < 0.001$; the highest average VW was provided by 'Isabell' - 765 g L^{-1}), and fungicide application ($p < 0.001$; in variants with fungicide application VW was 761 g L^{-1}). The impact of sowing rate on the average result of this indicator was insignificant ($p = 0.238$).

In **2018**, the VW was significantly affected only by the sowing time ($p < 0.0001$). Significant impact of other researched factors on VW was observed only in variants sown in some specific sowing times (Table 10).

Just like in the first trial year, the volume weight in the **second year (2019)** was affected by sowing time ($p < 0.0001$). Only in this year, the highest volume weight was obtained sowing beans in medium sowing time (on average 780 g L^{-1}) (Table 10). Volume weight was significantly affected also by the variety. The highest VW was always provided by the variety 'Isabel', but the differences of VW between 'Boxer' and 'Laura' were significant ($p < 0.0001$) when they were sown in early and medium sowing times (Table 10). Fungicide application increased the volume weight of field beans, but sowing rate did not have a significant ($p = 0.711$) impact on field beans' VW, similarly to results in 2018.

In the **third trial year (2020),** the VW was significantly affected by three researched factors: sowing time, variety, and fungicide application ($p < 0.0001$) (Table 10). The highest VW was observed for beans sown in early sowing time, but it did not differ significantly from VW observed when sowing beans in late sowing time ($p = 0.831$). Unexpectedly, significantly lower VW was observed sowing beans in medium sowing time ($p < 0.0001$) (Table 10). VW of 'Isabell' was always the significantly highest, but VW differences and their significance of 'Boxer' and 'Laura' depended on sowing time (Table 10). Fungicide application increased VW significantly ($p < 0.0001$).

Table 10. Volume weight (g L^{-1}) in field beans' seeds depending on researched factors, 2018–2020

Factors	Year and sowing time								
	2018 ($p < 0.0001$)			2019 ($p < 0.0001$)			2020 ($p < 0.0001$)		
	early	med*	late	early	med	late	early	med	late
Variety ($p_{2018} = 0.123$; $p_{2019} < 0.0001$; $p_{2020} < 0.0001$)									
Laura	780^{b}	769^{b}	734^{a}	757^{c}	775^{c}	772^{b}	740^{ab}	718^{c}	734^{b}
Boxer	782^{b}	773^{b}	731^{a}	763^{b}	779^{b}	776^{b}	736^{b}	728^{b}	730^{b}
Isabell	791^{a}	780^{a}	735^{a}	775^{a}	786^{a}	783^{a}	746^{a}	741^{a}	749^{a}
Sowing rate (germinable seeds m^{-2}) ($p_{2018} = 0.997$; $p_{2019} = 0.711$; $p_{2020} = 0.173$)									
30	784^{a}	772^{a}	735^{a}	767^{a}	780^{a}	778^{a}	737^{a}	728^{a}	735^{a}
40	784^{a}	775^{a}	733^{a}	765^{a}	779^{a}	776^{a}	741^{a}	730^{a}	737^{a}
50	785^{a}	774^{a}	732^{a}	765^{a}	781^{a}	777^{a}	743^{a}	729^{a}	742^{a}
Fungicide application ($p_{2018} = 0.186$; $p_{2019} = 0.001$; $p_{2020} < 0.0001$)									
F0	783^{a}	771^{b}	732^{a}	763^{b}	779^{a}	773^{b}	737^{b}	723^{b}	732^{b}
F1	786^{a}	777^{a}	735^{a}	768^{a}	781^{a}	781^{a}	744^{a}	735^{a}	744^{a}
Average	784^{A}	774^{B}	734^{C}	765^{B}	780^{A}	777^{A}	740^{A}	729^{B}	738^{A}

*med – medium; F0 – without fungicide application; F1 – with fungicide application.
Significantly different means are labelled with different letters in superscript: A, B, C – significant difference for average yields of three sowing times in a specific year; a, b, c – significant difference in a specific sowing time.

It was not possible to find other research results in studied literature illustrating VW dependency on sowing date. However, we obtained similar results to our previous findings (Plūduma-Pauniņa et al., 2018) regarding the impact of variety, research year and sowing rate on the VW.

Average **thousand seed weight (TSW)** was significantly affected by the trial year (Table 5; $p < 0.001$), and on average it was 511 g in 2018, 626 g in 2019, and 537 g in 2020. On average per all three trial years, sowing time, variety, and fungicide application affected TSW significantly ($p < 0.001$). The highest TSW was obtained sowing beans in early sowing time (579 g), but it decreased in succeeding sowing times, showing diverse results depending on the trial year. The variety 'Boxer' (574 g) provided the highest average TSW, and the average TSW was increased in variants with fungicide application. The impact of sowing rate on TSW was insignificant ($p = 0.143$) on average.

TSW during the **first trial year (2018)** was significantly affected by sowing time and variety (Table 11). The highest TSW on average (540 g) was observed in variants sown in early sowing time regardless of the variety used (Table 11). Sowing rate did not impact neither the average TSW ($p = 0.667$), nor that obtained in any of sowing time variants significantly. Although, the highest TSW in all cases was observed using 30 germinable seeds m^{-2} (on average 514 g). Fungicide application affected TSW in every sowing time variant significantly ($p < 0.01$), but these differences were not equipollent. Due to this, a significant impact of this factor on average TSW was not observed ($p = 0.256$; Table 11). However, fungicide application increased TSW when beans were sown in early and medium sowing time.

Despite the fact that the average TSW was the highest in the **second trial year (2019),** we observed similar impact of researched factors on this indicator. Sowing rate did not impact the average field beans' TSW ($p = 0.966$) significantly, but the effect of sowing time, variety and fungicide application was significant ($p < 0.0001$). Similarly to results a year before, the highest TSW was provided by variants sown in early sowing time, and TSW of the variety 'Boxer' was the highest on average (646 g). Fungicide application increased field beans' average TSW (652 g; + 52 g) significantly ($p < 0.0001$), and that in all sowing time variants (Table 11).

Similar effect of researched factors' on TSW was observed also in the **third trial year (2020)**, and it was significantly affected by sowing time, the field beans' variety used and fungicide application ($p < 0.0001$) (Table 11). Like in previous two trial years, sowing rate did not have a significant impact on the obtained TSW ($p = 0.429$).

Table 11. Field beans' 1,000 seed weight (g) depending on researched factors, 2018–2020

Factors	Year and sowing time								
	2018 ($p < 0.0001$)			2019 ($p < 0.0001$)			2020 ($p < 0.0001$)		
	early	med*	late	early	med	late	early	med	late
Variety ($p_{2018} = 0.001$; $p_{2019} < 0.0001$; $p_{2020} < 0.0001$)									
Laura	543^{b}	481^{b}	509^{a}	630^{b}	626^{b}	573^{a}	544^{b}	516^{b}	531^{a}
Boxer	556^{a}	492^{a}	514^{a}	672^{a}	667^{a}	600^{a}	573^{a}	555^{a}	539^{a}
Isabell	519^{c}	475^{b}	509^{a}	642^{b}	644^{b}	579^{a}	535^{b}	513^{b}	525^{a}
Sowing rate (germinable seeds m^{-2}) ($p_{2018} = 0.667$; $p_{2019} = 0.966$; $p_{2020} = 0.429$)									
30	541^{a}	484^{a}	516^{a}	651^{a}	644^{a}	579^{a}	556^{a}	532^{a}	533^{a}
40	540^{a}	481^{a}	511^{a}	648^{a}	648^{a}	585^{a}	550^{a}	528^{a}	535^{a}
50	538^{a}	483^{a}	506^{a}	645^{a}	645^{a}	588^{a}	547^{a}	524^{a}	527^{a}
Fungicide application ($p_{2018} = 0.256$; $p_{2019} < 0.0001$; $p_{2020} < 0.0001$)									
F0	533^{b}	473^{b}	520^{a}	629^{b}	627^{b}	545^{b}	529^{b}	511^{b}	507^{b}
F1	546^{a}	493^{a}	502^{b}	667^{a}	665^{a}	623^{a}	572^{a}	545^{a}	557^{a}
Average	540^{A}	483^{C}	511^{B}	648^{A}	646^{A}	584^{B}	551^{A}	528^{B}	532^{B}

*med – medium; F0 – without fungicide application; F1 – with fungicide application

Significantly different means are labelled with different letters in superscript: A, B, C – significant difference for average yields of three sowing times in a specific year; a, b, c – significant difference in a specific sowing time.

Wakweya et al. (2016) concluded that TSW increased with later sowing time, however, significant differences of TSW were not observed between four sowing time variants. While Manning et al. (2020) research resulted in the opposite direction - with later sowing dates the TSW decreased like in our study. In the two-year trial carried out in Jordan, Al-Rifaee et al. (2004) studied sowing rate effect on TSW, and obtained contradictory results. In the first trial year, significant difference between TSW depending on sowing rate was not found, but in the second trial year, using lower seeding rates, the TSW was higher. Similar result was obtained in some other researches (Stringi et al., 1988; Turk & Tawaha, 2002); our previous results about TSW dependency on sowing rate were contradictory (Plūduma-Pauniņa et al., 2018).

CONCLUSIONS

The changing meteorological conditions in three trial years had a significant and the highest impact on field beans' yield and quality. Although the earliest possible sowing time and, consequently, the medium and late sowing time varied between the different experimental years, the factor 'sowing time' had a significant effect on all the estimated parameters on average and mainly on all - in the given trial year.

The best yield on average was obtained, sowing beans in medium and early sowing timings, which conforms partly to previous recommendation to sow beans as early as possible. Crude protein (CP) content, although dependent on sowing time, varied within 1%, and it is not possible to conclude that there is a possibility to increase it importantly by choosing a specific sowing time. Higher volume weight (VW) and 1,000 seed weight (TSW) was obtained sowing beans in early sowing time.

The effect of the used variety on the obtained results varied depending on evaluated parameter. All three varieties gave similar yield on average per trial period, the variety 'Boxer' presented higher TSW, but the variety 'Isabell' had higher CP content in seeds and VW. It is not proved that a specific sowing time could be more suitable for performance of a certain variety.

In most cases the sowing rate affected only field beans' yield significantly, but the necessity for various sowing rates depending on sowing time was not proved. The highest yield was mostly obtained using the rate 50 germinable seeds per m^{-2}.

Fungicide application increased the obtained field beans' yield, VW and TSW significantly, but slightly decreased CP content in seeds.

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Discrimination of leaf diseases affecting faba bean (*Vicia faba*)

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ABSTRACT

Faba bean is susceptible to several leaf diseases caused by pathogenic fungi. With the increasing importance of faba bean in northern European cropping systems, the importance of its leaf diseases is likely to increase. The aim of this study was to discriminate the diseases and to test agronomic strategies for limiting their spread in a five-year experiment. Chocolate spot disease caused by *Botrytis* spp. and leaf blotches caused by an *Alternaria*/*Stemphylium* complex dominated, the severity of rust was lower, and downy mildew occurred in only one year. The severity of the diseases depended on weather conditions and cultivar, but not on sowing rate. Application of fungicides significantly decreased the severity of chocolate spot, leaf blotch and rust, but not downy mildew, and in no case was the disease progress stopped. None of the cultivars showed strong resistance to disease. The *Alternaria*/*Stemphylium* leaf blotch is an emerging disease of faba bean in northern Europe. Work continues on the identification of the responsible species in the chocolate spot and leaf blotch complexes and the determination of their relative importance in causing disease.

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Introduction

Faba bean (*Vicia faba* L.) is one of the most important grain legumes, with the highest global average grain yield after soybean (FAOstat 2020). Its importance in Europe is increasing (Eurostat 2020), partly as a result of efforts to reduce reliance on imported soy protein for feed use (Watson et al. 2017).

Faba bean is affected by a wide range of leaf diseases (Stoddard et al. 2010; Karkanis et al. 2018; Plūduma-Pauniņa et al. 2018). Of these, chocolate spot (caused by *Botrytis* spp.) is the most widely written about (Stoddard et al. 2010). According to bibliometric analysis, Ascochyta blight (caused by *Didymella fabae*) and rust (caused by *Uromyces viciae-fabae*) are of approximately equal importance. Leaf blights (caused by *Alternaria* spp. and *Stemphylium* spp.), Cercospora leaf spot (caused by *Cercospora zonata*) and downy mildew (caused by *Peronospora viciae* f. sp. *fabae*) are also found. Each disease has its environmental optima (Stoddard et al. 2010), so the dominant disease varies across regions and years.

Chocolate spot is attributable to at least three species of *Botrytis*: *B. fabae*, *B. cinerea* and *B. fabiopsis* (Zhang et al. 2010), and possibly others (Bankina et al. 2017). In some conditions, grey mould caused by

B. cinerea has been described as a separate disease (Boligłowa et al. 2016), but it is challenging to distinguish these pathogens under field conditions. Leaf blights caused by *Alternaria* spp. and *Stemphylium* spp. have become more widely observed in recent years, suggesting an increase in distribution and destructiveness (Sheikh et al. 2015; Vasić et al. 2019) and they are well established in the Baltic region (Plūduma-Pauniņa et al. 2019). *Alternaria alternata* and *A. tenuissima* are considered the main causal agents of Alternaria leaf blight, but other species have been found (Rahman et al. 2002; Coca-Morante and Mamani-Álvarez 2012). Similarly, several species of *Stemphylium* are associated with the disease on faba bean, including *S. botryosum*, *S. eturmiunum* and *S. vesicarium* (Sheikh et al. 2015; Caudillo-Ruiz et al. 2017; Vaghefi et al. 2020).

Meteorological conditions are one of the main limiting factors that affect disease development. In general, temperatures around 20 °C, free moisture on the leaves and high (<90%) relative humidity are optimal conditions for the development of most leaf blotch diseases (Harrison 1988; Stoddard et al. 2010; Salam et al. 2016; Watson et al. 2017). Disease development depends also on agronomic practices, with high crop density increasing the spread of disease by reducing transmission distances and increasing canopy humidity, while intercropping can reduce the spread by intercepting propagules on non-susceptible species (Stoddard et al. 2010). Genetic resistance to diseases is the ideal way to control them, but few sources of strong or long-lasting resistance to any disease have been found in faba bean (Stoddard et al. 2010; Ijaz et al. 2018; Sudheesh et al. 2019). Hence, fungicide application is often the only available tool for controlling disease development and azoles, strobilurins and dithiocarbamates are considered effective against several leaf diseases of faba bean (Ahmed et al. 2016).

With the increasing importance of faba bean in northern European cropping systems, the importance of its leaf diseases is likely to increase. Hence, we set out to discriminate the diseases from each other, to evaluate their relative importance and to test agronomic strategies for limiting their spread in a five-year experiment.

Materials and methods

Field trials were conducted from 2015 to 2019 at the Pēterlauki Research and Study Farm of the Latvia University of Life Sciences and Technologies (56.54 °N, 23.71 °E). The prevailing soil type is silty loam characterised as an Endocalcaric Abruptic Luvisol. Disease assessment was part of a larger experiment investigating agronomic strategies for optimising yield of faba bean. Data about disease development were obtained from a three-factor experiment: cultivar ('Isabell'; 'Boxer' and 'Laura'), sowing rate (30, 40 and 50 germinable seeds m^{-2}) and fungicide (combined boscalid, 267 g kg^{-1} and pyraclostrobin, 67 g kg^{-1} application or without fungicide), with four replicates in a full factorial, randomised split block. Sowing dates were 26 March 2015, 5 April 2016, 4 April 2017, 29 April 2018 and 15 April 2019. Harvest dates were 27 August 2015, 29 August 2016, 24 September 2017, 13 August 2018, and 29 August 2019. Detailed descriptions of the trial site and agronomic practices have been published (Plūduma-Pauniņa et al. 2018; Plūduma-Pauniņa et al. 2019).

Diseases were identified by visual evaluation when symptoms were typical and by microscopic evaluation of spores obtained from infected tissues.

Severity of diseases were evaluated on a 10-point scale (0: no disease symptoms, 1: 1–3 spots on the whole plant; 2: 4–6 spots on the plant; 3: up to 10% of the whole plant covered by spots; 4: 11–25% of the whole plant covered by spots; 5: 26–50% of the whole plant covered by spots; 6: 51–75% of the whole plant covered by spots; 7: >75% of the whole plant covered by spots; 8: all leaves covered with spots; 9: plant is dead) every two weeks from the time of appearance of first symptoms until crop maturity. Areas under the disease progress curves (AUDPC) were calculated (Simko and Piepho 2012).

Temperature and amount of precipitation were recorded daily by an automatic weather station near the experimental field (Table 1) and the hydrothermal coefficient (HTC) was calculated (Vlăduţ et al. 2017) when the daily average temperature was above 10 °C (Table 1). Values of HTC close to 0.9–1.1 are considered as optimal conditions, values above 1.1 as wet, and those below 0.9 as dry.

Table 1. Average temperature (°C), amount of precipitation (mm) and hydrothermal coefficient (HTC) during the growing season at the Pēterlauki Research and Study farm of the Latvia University of Life Sciences and Technologies. (Table view)

Month	Decade	2015			2016			2017			2018			2019		
		°C	mm	HTC	°C	mm	HTC	°C	mm	HTC	°C	mm	HTC	°C	mm	HTC
April	I	4.3	16.0	3.8	7.2	9.0	1.3	7.6	2.5	0.3	6.4	35.5	5.6	5.2	0.0	0.0
	II	6.2	16.5	2.7	7.0	21.5	3.1	2.0	11.0	5.5	10.5	14.0	1.3	5.7	0.0	0.0
	III	9.5	24.6	2.6	5.7	32.5	5.7	4.8	25.0	5.2	10.1	20.0	2.0	13.4	0.0	0.0
May	I	10.6	11.4	1.1	14.0	0.2	0.0	7.7	1.0	0.1	13.8	8.0	0.6	8.1	5.2	0.6
	II	9.8	25.4	2.6	12.2	20.5	1.7	12.4	6.5	0.5	16.4	4.0	0.2	14.2	10.0	0.7
	III	12.2	17.7	1.3	17.0	15.0	0.8	14.4	16.0	1.0	17.9	0.0	0.0	14.7	5.8	0.4
June	I	14.5	1.0	0.1	14.0	18.0	1.3	13.7	24.0	1.8	16.3	2.0	0.1	19.3	3.0	0.2
	II	15.2	4.7	0.3	15.4	22.5	1.5	16.5	13.5	0.8	18.2	1.0	0.1	20.6	3.2	0.2
	III	14.6	10.0	0.7	21.0	47.0	2.2	15.0	12.0	0.8	15.9	12.6	0.8	18.4	4.6	0.3
July	I	18.5	27.2	1.5	18.0	80.0	4.4	14.8	43.0	2.9	16.7	16.4	1.0	14.9	29.0	2.0
	II	15.6	27.5	1.8	17.8	20.0	1.1	15.9	23.0	1.4	22.2	16.2	0.7	16.0	48.2	3.0
	III	16.5	19.3	1.1	20.1	45.0	2.0	19.1	17.0	0.8	23.7	1.0	0.0	19.4	23.8	1.1
August	I	20.4	1.0	0.0	17.4	66.1	3.8	18.2	22.2	1.2	23.4	6.0	0.3	15.5	31.6	2.0
	II	17.6	1.8	0.1	16.9	45.5	2.7	17.1	4.8	0.3	18.5	13.2	0.7	18.5	1.4	0.1
	III	18.5	2.9	0.2	17.2	17.0	1.0	15.0	4.0	0.3	16.7	9.2	0.6	18.5	4.8	0.3

Multifactorial analysis of variance (ANOVA) was used to evaluate the influence of year, cultivar, sowing rate and fungicide use on the development of faba bean diseases using R software. The differences among factor groups were compared using Bonferroni test with an alpha level of 0.05.

Results

Symptoms and disease identification

Chocolate spot disease was detected every year. Typical small reddish-brown spots and/or large necrotic blotches with reddish margins were observed on the leaves, stems and pods (Figure 1). In some cases, small black sclerotia were found, mostly on the pods. In wet conditions, blotches were covered with powdery grey mould that consisted of conidiophores and conidia (Figure 1.)

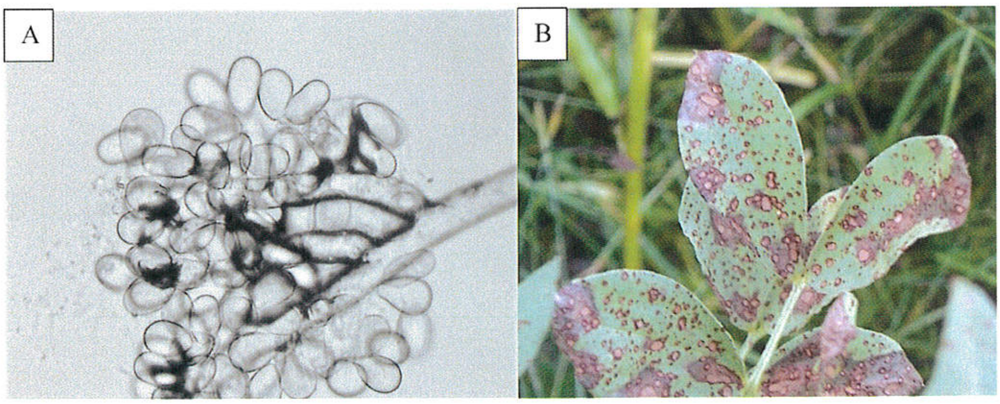

Figure 1. *Botrytis* spp., (A) conidiophores and conidia (magnification × 40) and (B) symptoms of chocolate spot disease on a leaf.

Large, grey to black, necrotic and fused blotches were also observed on leaves every year (Figure 2). The symptoms were typical of either *Alternaria* or *Stemphylium*, so diagnosis via microscopy was necessary. Spores typical of both genera *Alternaria* and *Stemphylium* were found, indicating that they were the causal agents (Figure 3). It was not possible to distinguish the blotches caused by one or the other pathogen under field conditions, and both pathogens were isolated from the same plants and same blotches, so this disease appears to have been caused by a complex of the two pathogens and was called *Alternaria/Stemphylium* leaf blotch.

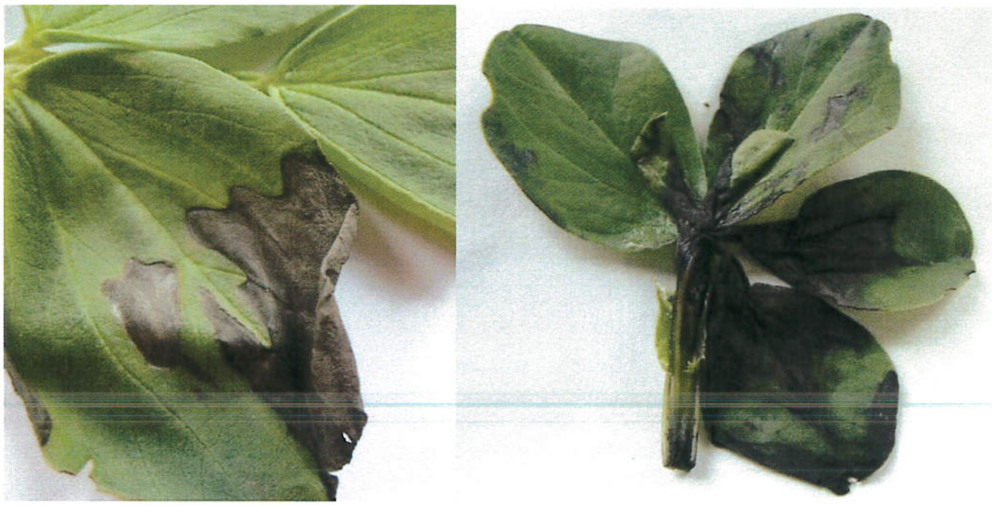

Figure 2. Symptoms of the leaf blotch, caused by *Alternaria/Stemphylium* complex.

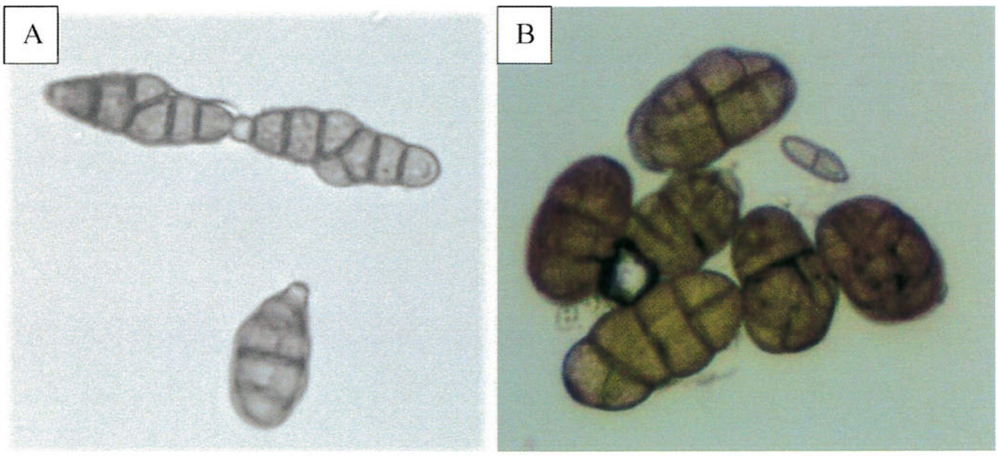

Figure 3. Conidia of (A) *Alternaria* sp. and (B) *Stemphylium* sp. (magnification × 40).

Rust infected plants every year, and was identified by its distinctive and bright orange uredo-pustules.

Downy mildew formed blotches with reddish tint on the underside of leaves in 2017 and conidiophores typical of genus *Peronospora* were found (Figure 4).

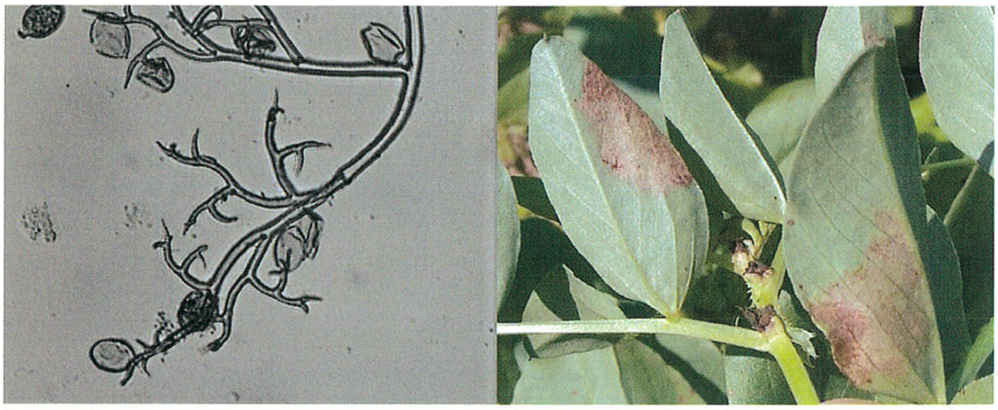

Figure 4. *Peronospora viciae*, (A) sporophores with sporangia (magnification × 40) and (B) symptoms of downy mildew disease on a leaf.

Seasonal progress of diseases

The first symptoms of both chocolate spot and leaf blotch were observed in early June, before the start of flowering. In most years, rapid disease development started in July (end of flowering to development of pods), except in 2016, when the progress of disease started earlier (Figures 5 and 6); in this season, the faba beans developed earlier and ended flowering at the end of June.

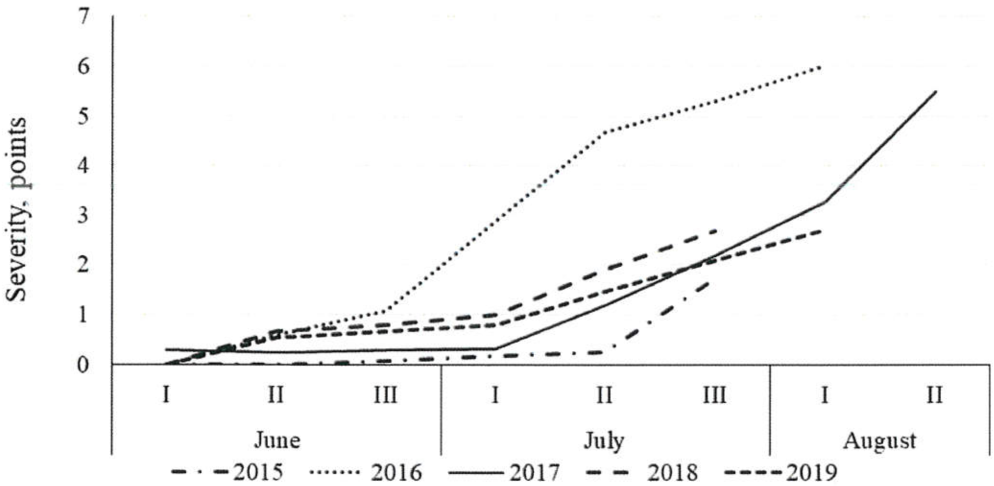

Figure 5. Dynamics of development of chocolate spot, caused by *Botrytis* spp. in untreated plots. Data show means across cultivars and plant densities.

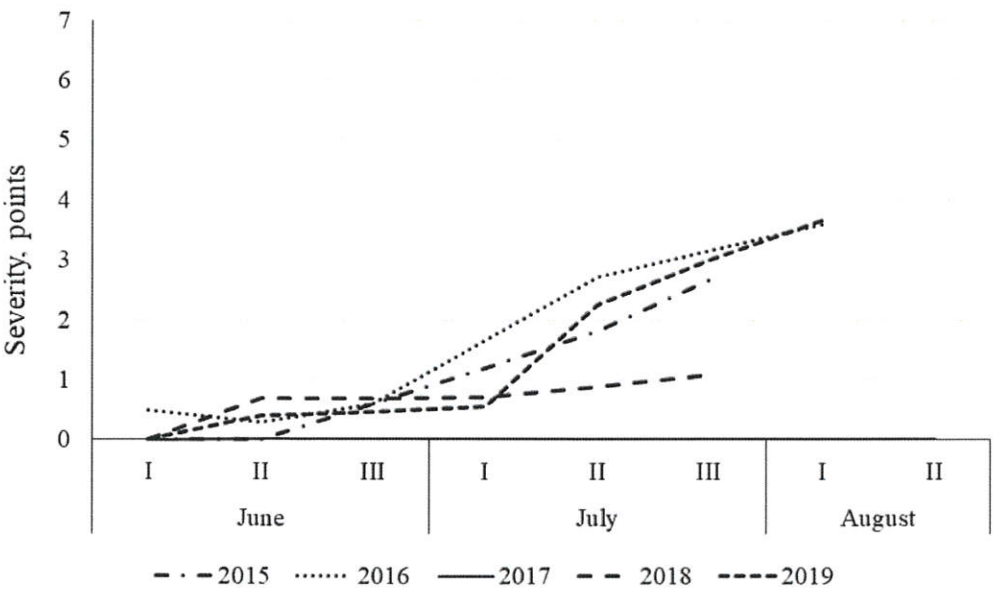

Figure 6. Dynamics of development of leaf blotch (caused by *Alternaria/Stemphylium* complex) in untreated plots. Data show means across cultivars and plant densities.

Rust appeared during pod development and its scores remained low, failing to reach 1 point until August. Downy mildew was found only in 2017 and the first symptoms were seen in the third decade of July (development of pods). During pod ripening, disease severity ranged from 1.2 to 2.4 points.

The AUDPC differed widely between years ($p < 0.0001$) (Figure 7). The highest values for chocolate spot, leaf blotch and rust were observed in 2016. The lowest severity of chocolate spot was in 2015, only traces of leaf blotch were observed in 2017, and rust was not detected in 2018.

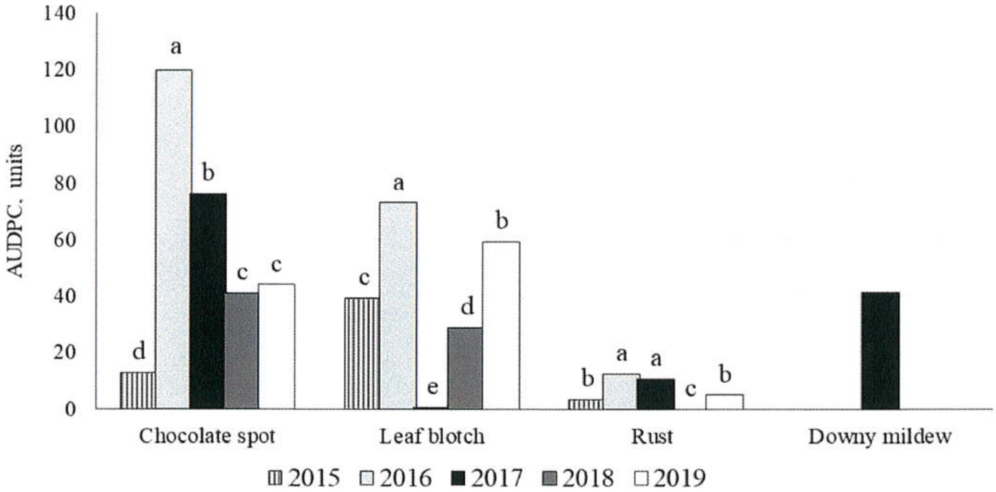

Figure 7. Development of faba bean leaf diseases as AUDPC, depending on year (2015–2019) in untreated plots. Data show means across cultivars and crop densities. Significantly ($p < 0.001$) different means within a year are labelled with different letters.

Cultivars showed differences in AUDPC averaged across years ($p < 0.001$ for leaf blotch and $p < 0.0001$ for the other diseases), but none could be classified as resistant (Figure 8). Cultivar 'Laura' was the most sensitive to all observed diseases, whereas 'Boxer' was least sensitive to downy mildew but equal to 'Laura' in sensitivity to *Alternaria/Stemphylium* leaf blotch and chocolate spot. 'Isabell' was least sensitive to chocolate spot.

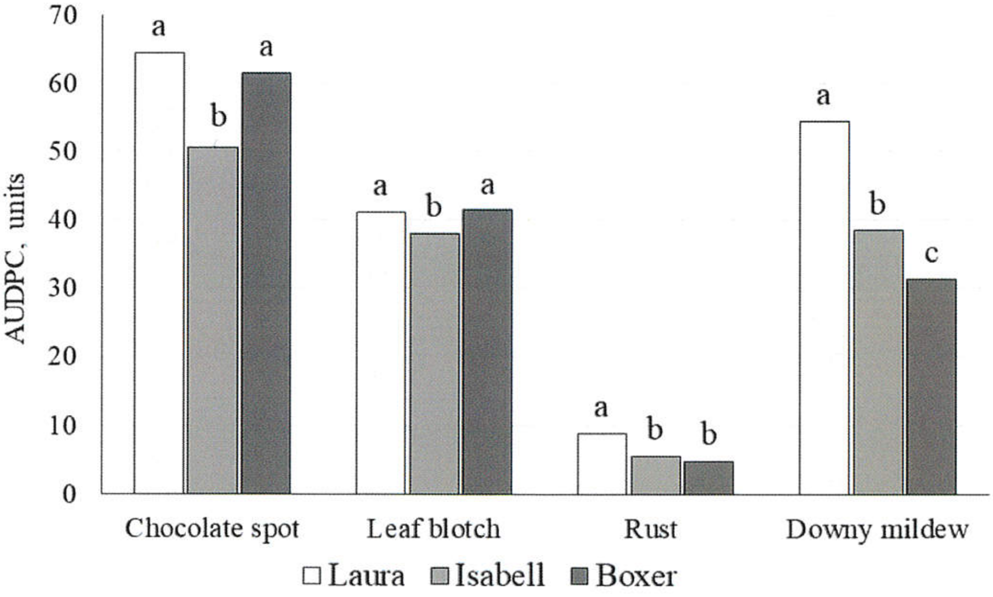

Figure 8. Development of faba bean leaf diseases as AUDPC, depending on cultivar in untreated plots. Data

show means across years and crop densities. Significantly ($p < 0.001$) different means within a disease are labelled with different letters.

Fungicide application decreased the AUDPC of all diseases ($p < 0.0001$), except downy mildew ($p > 0.05$) (Figure 9).

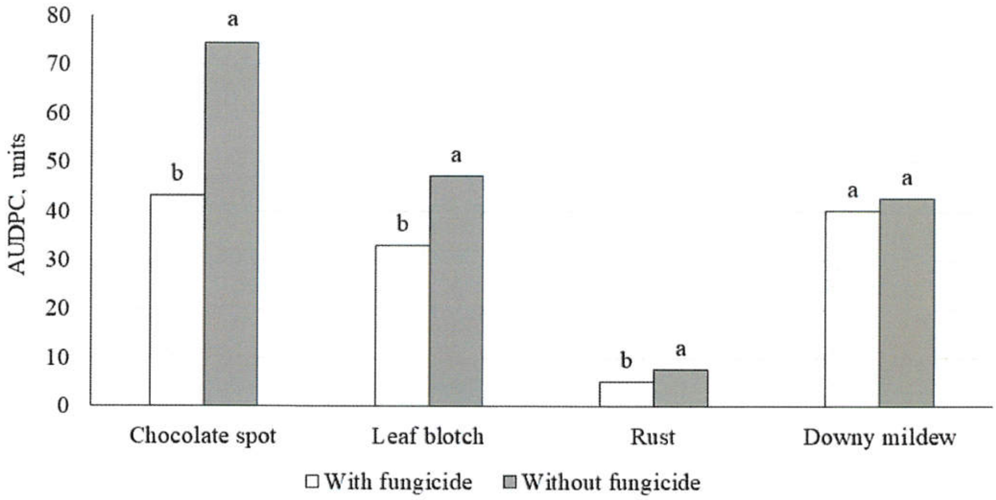

Figure 9. Development of faba bean leaf diseases depending on fungicide application. Data show means across years, crop densities and cultivars ($p > 0.05$ for downy mildew; $p < 0.0001$ for other diseases). Different letters indicate significance of difference between treatments within a disease.

Seed rate did not influence the development of any of the diseases.

Treatment interactions were not statistically significant.

Discussion

During the course of this experiment, chocolate spot was the most prevalent disease, followed by Alternaria/Stemphylium leaf blotch, while rust was minor and downy mildew was found in only one year (Figure 7). In two of the five years, leaf blotch symptoms were more severe than those of any other disease, indicating the need for improved knowledge about this parasite complex and how it may be controlled.

The ubiquity of chocolate spot disease was according to expectations, as was its moderate impact in three of the five years. It was most severe, with the disease severity approaching 6 (>50% of leaf area covered with spots), in 2016 and 2017. This was associated with a high HTC and heavy rainfall in early July of both years, confirming the importance of leaf wetness for the spread of this disease (Stoddard et al. 2010). Furthermore, the cool weather in July and August 2017 was associated with prolonged growth of the crop and availability of green leaves for the disease to spread, as shown by the prolonged disease score curve for that year (Figure 5). In contrast, the cool and dry weather of 2015 was associated with a low incidence of this disease.

Leaf blotch caused by *Alternaria* and *Stemphylium* spp. was observed in every year except 2017. Symptoms of *Alternaria* infection have been described as slowly increasing brown spots with concentric rings, often water-soaked (Rahman et al. 2002; Abd El-Hai 2015) while those of *Stemphylium* infection are large, grey to black spots growing from the leaf margins (Vaghefi et al. 2020). In the present work, the leaf spots were large, dark and shapeless as the result of coalescence of smaller spots (Figure 2), thus showing some of the symptoms of both pathogens. Furthermore, both genera were recovered from the spots. In Australia, although two species of *Stemphylium* were recovered from leaf spots on faba bean, only some isolates of one (*S. eturmiunum*) were pathogenic in subsequent tests, and the same may be true here. In Bolivia, several species of *Alternaria* were mentioned as causal agents of leaf blotch (Coca-Morante and Mamani-Álvarez 2012). Both genera have been found to cause significant crop damage, with more than 90% of plants affected by *Alternaria* in some fields in Japan (Rahman et al. 2002) and lethal damage attributed to *S. eturmiunum* in Australia (Vaghefi et al. 2020). Neither genus is identifiable to species level by morphological tools alone, and DNA sequence data has been used for species identification in both *Alternaria* (Woudenberg et al. 2013) and *Stemphylium* (Vaghefi et al. 2020).

In the present study, the leaf blotches were found before flowering, similar to the timing of *Stemphylium* leaf blotch in Australia (Vaghefi et al. 2020) and *Alternaria* leaf spot in Japan (Rahman et al. 2002). Although the maximum severity of *Alternaria/Stemphylium* leaf blotch was only 3.7 points, in contrast to 6.0 for chocolate spot, the AUDPC of leaf blotch exceeded that of chocolate spot in both 2015 and 2019 (Figures 5 and 6). In both these years, the mean summer temperature was slightly lower and the rainfall was much lower than in 2016, the year that was particularly favourable for chocolate spot. The absence of leaf blotch in 2017 was associated with the strong presence of downy mildew and it is not possible to determine whether the absence was due to poor conditions or to the presence of the other disease. Taken together with results from several countries in different climatic zones, our results indicate that this disease complex is important and tools for its control need to be developed.

Rust disease was found every year, but only after flowering and its severity did not exceed one point. Rust is not considered a devasting disease in northern Europe, but it is an important problem in dry and warm climates (Sillero et al. 2006; Ijaz et al. 2018).

Downy mildew was found only in 2017, so it is difficult to make any conclusions about occurrence and harmfulness of this disease in the Baltic region. The 2017 growing season had the lowest mean temperature of the five years of experiments, particularly in early July temperature when the rainfall was also plentiful, leading to a combination of relatively low temperature and high humidity that is favourable for the development of this disease (Stegmark, 1994; Stoddard et al. 2010). Downy mildew is a common problem on spring-sown faba bean in the United Kingdom (Thomas et al. 1999).

There were only small differences between cultivars in response to the various diseases (Figure 8). Genetic resistance to chocolate spot disease is partial at best (Bouhassan et al. 2004) and knowledge about cultivar differences in response to *Alternaria / Stemphylium* leaf blotch is still very limited (Sheikh et al. 2015). The fact that both chocolate spot and leaf blotch are caused by several related pathogens with possibly different modes of infection is likely to impede breeding for resistance until more is known about both the pathogens and the host responses.

Seed rate did not influence the development of any diseases in our investigations. Optimal seed rate is often considered as an important tool to reduce the development of leaf diseases, because high density promotes high air humidity and leaf wetness (Stoddard et al. 2010), although Doussoulin et al. (2015) did not find correlation between density of plants and severity of diseases. Nevertheless, the relatively low seed rates in the current experiment (30–50 m^{--2}) may not have been enough to cause problems.

The fungicide combination (boscalid and pyraclostrobin) provided partial protection against chocolate spot, *Alternaria/Stemphylium* leaf blotch and rust on average (Figure 9), but efficacy depended on year and cultivar, with greater effectiveness in years when pathogen pressure was greater. These fungicides are not considered effective against oomycetes, so their lack of effect on downy mildew was expected.

In conclusion, these experiments have shown that *Alternaria/Stemphylium* leaf blotch is an emerging disease of increasing importance on faba bean in northern Europe, as also demonstrated in other countries, and that it is comparable in impact to chocolate spot disease. Each disease complex has its optima of temperature and moisture, so it should be possible to develop forecasts for the timing of disease control interventions such as the use of fungicides. The diseases are easily distinguished by their typical symptoms. Lowering crop density was not an effective tool to reduce disease incidence and fungicide application was only partly successful. Better sources of resistance are needed if the diseases are to be controlled by genetic means. Work continues on the identification of the responsible species in the chocolate spot and leaf blotch complexes and determination of their relative importance in causing disease.

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