APPLIED CROP PROTECTION 2018

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AARHUS UNIVERSITY
DCA - DANISH CENTRE FOR FOOD AND AGRICULTURE

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Supplementary information and clarifications (October 2019)

In an effort to ensure that this report complies with Aarhus University's guidelines for transparency and open declaration of external cooperation, the following supplementary information and clarifications have been prepared in collaboration between the researcher (s) and the faculty management at Science and Technology:

The Publication Applied Crop Protection is a yearly report providing output to farmers, advisors, industry and researchers in the area of crop protection. The publication typically summarizes data, which is regarded to be of relevance for practical farming and advice. It covers information on the efficacy profiles of new pesticides, effects of implementation of IPM principles (integrated pest management) aiming at reducing the use of pesticides and illustrates the use of Decision Support Systems (DSS) in combination with resistant cultivars. It also includes an update on pesticides resistance to ensure that only effective strategies are used by the farmers to minimize build-up of resistance.

The report was initiated in 1991, when Danish Research Service for Plant and Soil Science (Statens Planteavlsforsøg) as part of the Ministry of Agriculture was responsible for biological testing of pesticides and provided a certificate for biological efficacy based on the level of efficacy in field trials. Later this system was replaced by EU's rules for efficacy data. Efficacy testing of pesticides was opened up to all trial units, which had obtained a GEP approval (Good Efficacy Practice) and fulfilled the requirements based on annual inspections.

Since 2007 the report has been published by Aarhus University (AU) and since 2015 it has been published in English to ensure a bigger out-reach. The choice of topics, the writing and publishing of the report are entirely done by staff from Aarhus University and the report content is not shared with the industry before publication. All authors and co-authors are from AU. The data on which the writing is based is coming from many sources depending on the individual chapter. Below is a list with information on funding sources for each chapter in this report.

Chemical companies have supplied pesticides and advice on their use for the trials and plant breeders have provided the cultivars included in specific trials. Trials have been located either on AU's research stations or in fields owned by private trial hosts. AU has collaborated with local advisory centres and SEGES on several of the projects e.g. when assistance is needed regarding sampling for resistance or when looking for specific localities with specific targets. Several of the results have also been published in shared newsletters with SEGES to ensure a fast and direct communication with farmers.

Chapter 1: Climate data for the growing season 2017/2018 and specific information on disease attack 2018
Information collected by AU.

Chapter 2: Disease control in cereals
Trials in this chapter have been financed by ADAMA, Corteva, Bayer Crop Science, BASF, Syngenta, Nordic seed, KWS and Sejet Plantbreeding, but also certain elements have been based on AU's own funding.

Chapter 3: Control strategies in different cultivars
Trials in this chapter have been financed by income from selling the DSS system Crop Protection Online, as well as input from Bayer Crop Science and BASF. Certain elements have been based on AU's own funding as part of a PhD project (Rose Kristoffersen).

Chapter 4: Fungicide resistance-related investigations
Testing for fungicide resistance is carried out based on a shared cost covered by projects and the industry. In 2018 ADAMA, Corteva, Bayer, BASF and Syngenta were involved from the industry. The Swedish part is financed by Swedish Board of Agriculture and also money from Jullerupfonden and AU-agro have been included.

Chapter 5: Control of late blight (Phytophthora infestans) and early blight (Alternaria solani) in potatoes
Trials in this chapter have been financed by income from Nordisk Alkali, Bayer, BASF, Syngenta. Certain elements have been based on AU's own funding as part of a PhD project (Isaac Abuley). Several of the trial plans have been carried out in collaboration with SEGES, which include the testing of DSS.

Chapter 6: Influence of adjuvants on the activity of glyphosate products
The project was financed by agricultural tax funds (promilleafgiftsmidler) via SEGES.

Chapter 7: Liquid nitrogen as an adjuvant to ALS-inhibitors
The project was financed by agricultural tax funds (promilleafgiftsmidler) via SEGES.

Chapter 8: Influence of weed growth stage and moisture stress on the efficacy of glyphosate
The project was financed by agricultural tax funds (promilleafgiftsmidler) via SEGES.

Chapter 9: Longevity of seeds of blackgrass following different stubble cultivation treatments
The project was financed by agricultural tax funds (promilleafgiftsmidler) via SEGES.

Chapter 10: Results of crop protection trials in minor crops in 2018
The project was financed by various agricultural tax funds, GUDP, chemical companies, Swedish minor use funding.

Chapter 11: Results from testing of herbicides, growth regulators and desiccants in agricultural crops in 2018
The trials presented was financed by the chemical company Nufarm.

Chapter 12: GRRC report: Puccinia striiformis race analyses molecular genotyping 2018
The project was financed by a broad range of partners including Melinda &Bill Gates foundation, UK department of International development, FAO, EU project Rust watch under horizon 2020, Swedish Board of Agriculture) and Aarhus University.

Chapter 13: Susceptibility of winter wheat cultivars exposed to races of yellow rust in inoculated field trials in Denmark
The project was financed by Swedish Board of Agriculture and Aarhus University.

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Scientific report

The reports contain mainly the final reportings of research projects, scientific reviews, knowledge syntheses, commissioned work for authorities, technical assessments, guidelines, etc.

Contents

Preface

This report contains results from crop protection trials in agricultural crops carried out mainly in demo trials and focuses to a major extent on results with different pesticides. To a great extent the results are presented through graphics and in the form of tables. Trial results from specific IPM-related activities which are not specifically related to pesticides are also included.

The report also gives a description of the climate as well as the pest incidence in the crops. The report is a summary of the publicly available results generated every year by the Department of Agroecology. The results include different surveys of pathogens carried out relating to cultivar susceptibility, results from new pesticides or pesticides already on the market. Results are included in the annual update of the advisory programme “Crop Protection Online”. Many of the results in this year’s report are results from single trials or trial series. Trials from several years are also summarised in several cases.

The report was compiled and edited by Lise Nistrup Jørgensen, Department of Agroecology, Aarhus University, Flakkebjerg, Denmark in collaboration with other scientists in the team at Flakkebjerg.

Thanks are due to all who have contributed to generating the results described in this report. Special acknowledgement is given to the chemical companies selling pesticides, private trial hosts, staff at local advisory centres, SEGES and staff at the Department of Agroecology.

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I Climate data for the growing season 2017/2018

Helene Saltoft Kristjansen

The growing season (Sept. 2017–Aug. 2018) began with a high amount of rain; especially September and October turned out to be two months in which precipitation was far above normal. For the two months, precipitation reached a cross-country average of 109/106 mm, respectively. Both months exceeded normal precipitation by 49/39%. The average precipitation in September-November for the country in general was 290 mm, which was 27% above normal and the highest precipitation recorded since 1984.

Due to a late summer harvest and a wet autumn, winter crop establishment was delayed. The average area sown with winter crops in 2017/2018 was considerably decreased compared to the last 12 years.

The autumn temperatures measured reached an average level of 10.0°C, which was 1.2°C above normal. A warm October with an average temperature of 11.1°C increased the autumn temperature average. The first frosty days were recorded in early October, and the number of frosty days in the autumn was 5.4 days, mainly in November.

The average temperature during the winter was 1.9°C, which was 1.4°C above normal. Consecutive hours (24) with frost occurred 45 times during the winter 2017-18, which was below normal (53 times). Winter weather came in February, and the number of days with frost exceeded 23 days. Only 6.5 days with snow were recorded during the winter, which was far below normal (26.4 days). Precipitation during the winter was 9% above normal due to high precipitation in January: 82 mm, which was 44% above normal.

Spring 2018 started out cold; 23 days with frost were measured in March together with a snow cover for 7.5 days. Nevertheless, the spring (2018) was sunny and warm. The temperature average reached 7.9°C, which was 1.7°C above normal. Both April and May temperatures exceeded normal temperatures and reached an average of 8.4/15.0°C, which was 2.7/4.2°C above average. Precipitation in April was quite high, an average of 54 mm, which was 32% above normal. May was sunny and dry with only 18 mm rain, which was 63% less than normal.

The summer (2018) was the warmest since 1874 and the sunniest summer recorded since 1920. Lack of precipitation was significant. On average, the lack of precipitation in the summer months reached 25%, and severe drought in June and July was fatal for crop yields. The precipitation in June/July was 24/17 mm, which was 56/74% less than average. The temperatures reached an average of 17.7°C, which was 2.5°C above average.

At Flakkebjerg, the autumn and winter (September–February) were above average in temperature, and September, October and January had higher precipitation: 100/80/76 mm, which was 40/24/28 mm above normal precipitation in autumn/winter. Due to the challenging weather conditions, winter cereal crops were sown in late autumn (October), and due to difficult sowing conditions in wet soil, crop establishment was relatively poor. The first frosty days did not occur until January. On average, winter month temperatures were close to average, but January and February showed temperatures below normal and low temperatures continued during March. The snow cover during the winter was limited to a few days in February and March. The spring had a surplus of precipitation in March and April, and together with high temperatures in April this ensured a good establishment of the spring crops. The high temperatures continued during May and lasted through June and July. High temperatures during the summer together with a severe lack of precipitation during the growing season had an adverse influence on growth, diseases and yield in all crops (Figure 1). Due to drought, irrigation started early, and the need for repeated irrigation continued all summer. In general, fungicide trials at Flakkebjerg were irrigated 2-3 times during the summer. On average, the lack of precipitation in May, June and July reached -116 mm - the normal average is -56 mm (Figure 2). The harvest of the crops was generally easy, and most crops were harvested by the second week in August under dry conditions. Winter cereal yields were maintained due to irrigation, but crops were uneven as a result of poor establishment and periods with drought (Figure 3). Spring crop yields were heavily reduced.

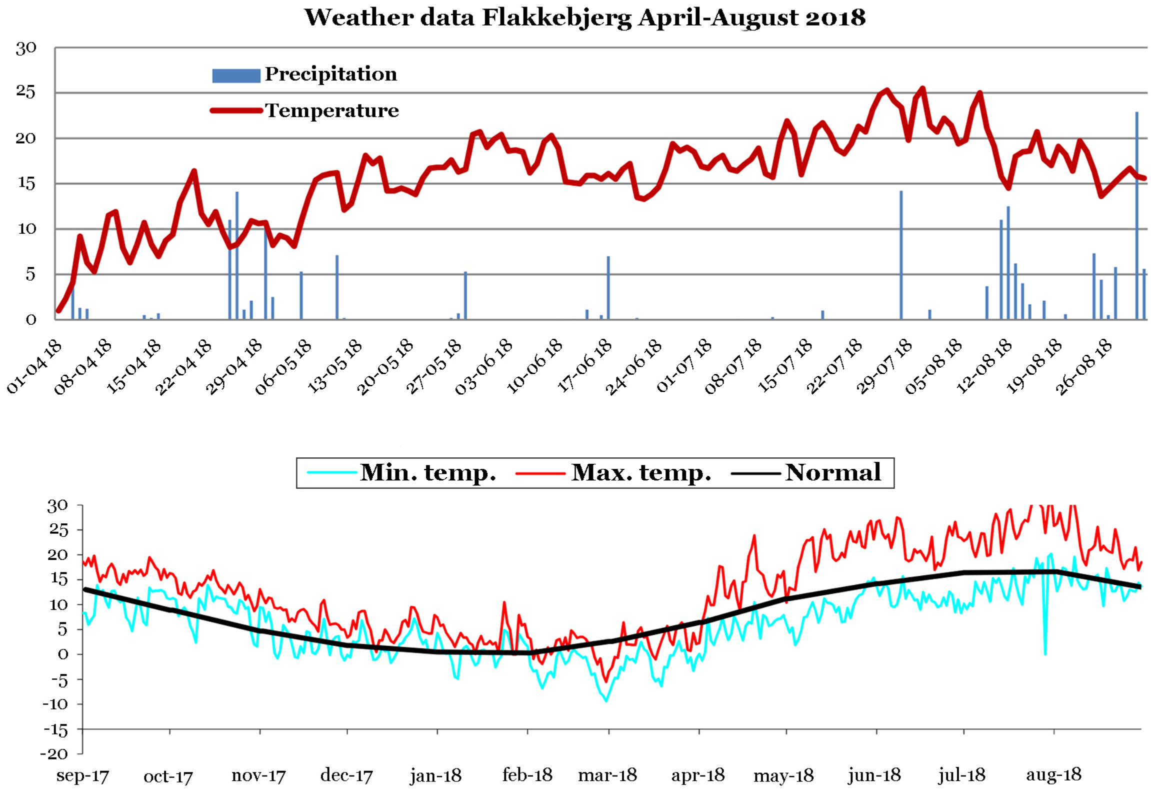


Figure 1. The automatic weather station at Flakkebjerg is located 12 km from the West Zealand coast. The climate at Flakkebjerg is representative of the area in which most of our trials are situated. The normal climate is given as an average of thirty years (1973-2003).

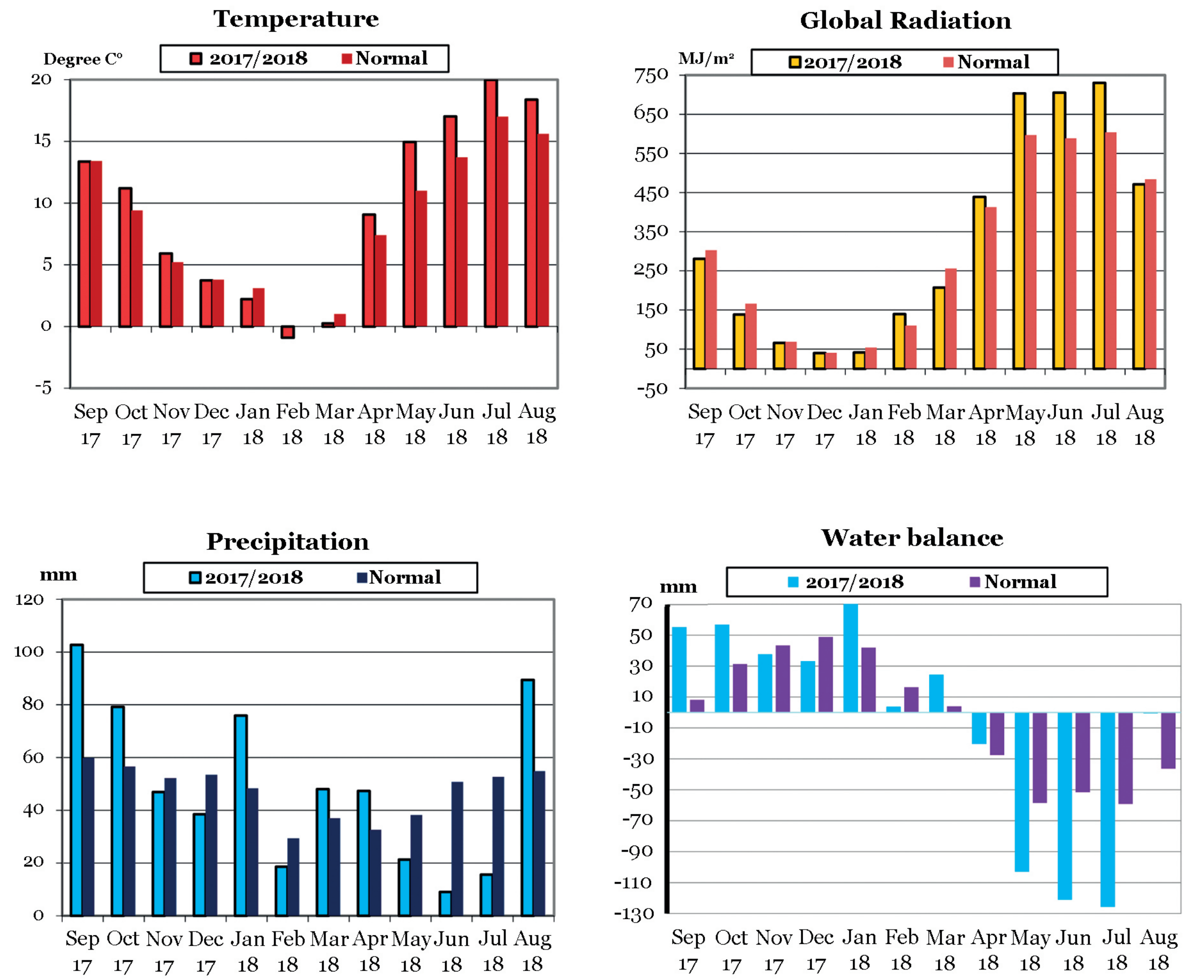
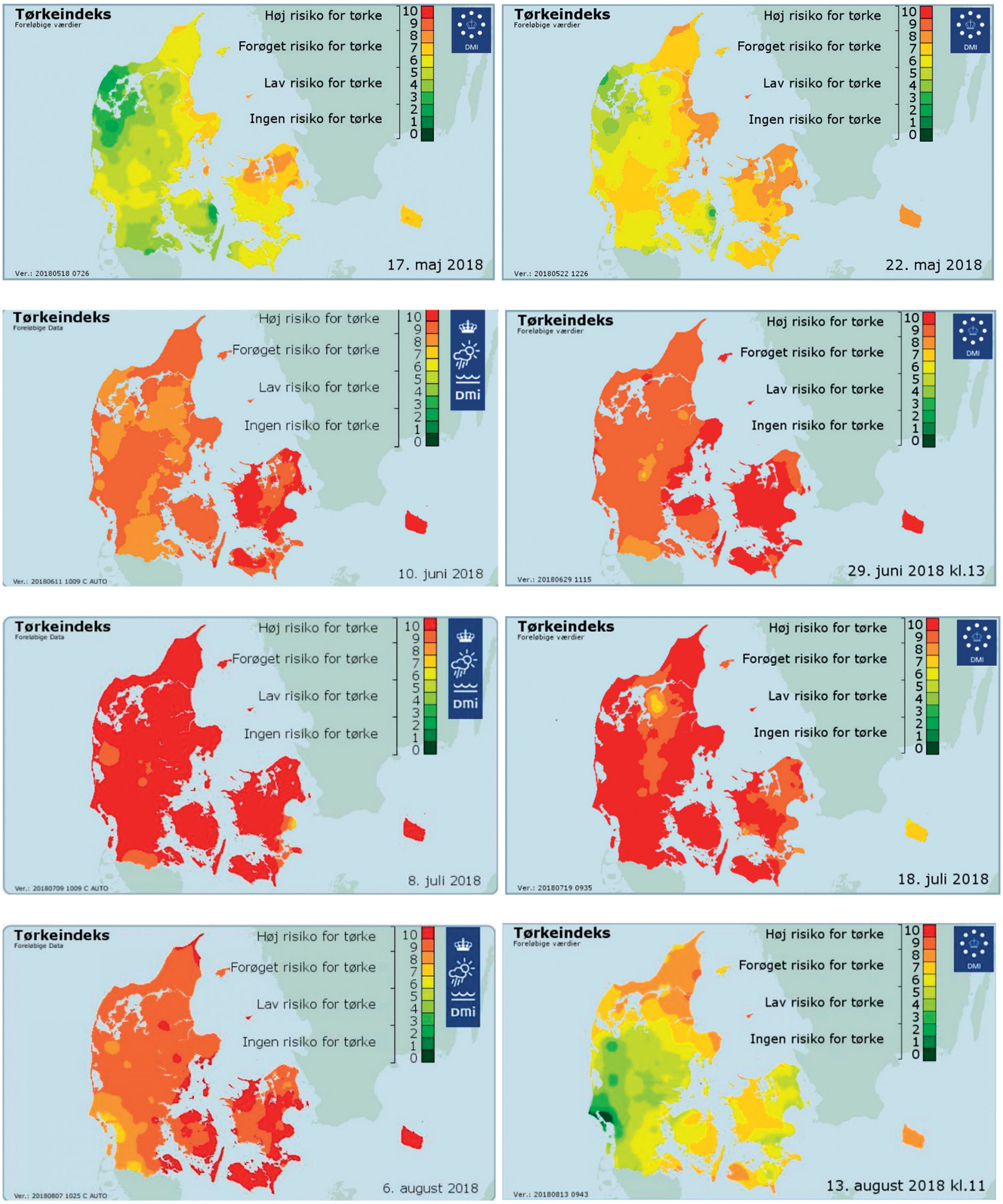


Figure 2. Climate data from Research Centre Flakkebjerg for the growing season September 2017-August 2018. The temperature is in °C, the global radiation measured in MJ/m², the precipitation in mm, and the water balance is the difference between precipitation and potential evaporation.



Drought index 2018 (DMI)

Scale:

- 0-2 No risk of drought (green)
- 3-5 Low risk of drought
- 6-8 Increased risk of drought
- 9-10 High risk of drought (red)

Figure 3. Drought index for May-August 2018. Danish Meteorological Institute (DMI).

1. Disease attacks in 2018

Lise Nistrup Jørgensen, Bent J. Nielsen, Niels Matzen, Helene Saltoft Kristjansen, Hans-Peter Madsen & Malthe Oksen Adserballe

In this chapter, information is presented about the diseases occurring in the trials carried out in 2018. This makes it possible to evaluate if the target diseases were present at significant levels and whether or not trials gave representative results. Yield levels in cereal trials were also ranked and compared with the previous year's responses.

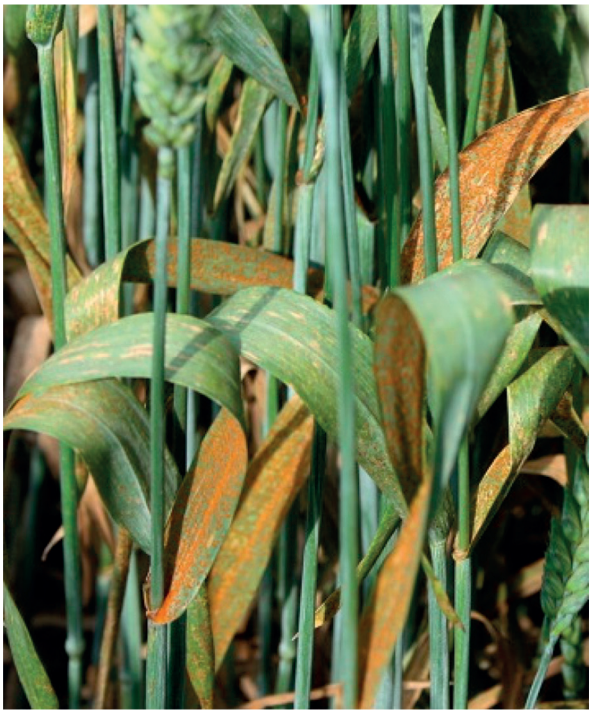
Wheat

Powdery mildew (*Blumeria graminis*). Severe attacks of mildew attacks developed in the mildew specific trials at Jyndevad. The sandy soil in Southern Denmark is well known for its severe attacks of powdery mildew, and in 2018 severe attacks developed as expected. For the country in general, the level of mildew attack was low due to the dry weather. Minor attacks were recorded during May, especially in the cultivar Torp. Recordings carried out by the advisors in the national monitoring system organised by SEGES also showed low to moderate levels of attack this year.

Septoria leaf blotch (*Zymoseptoria tritici*). The level of *Septoria* attack varied and depended on sites and cultivars but in general the level of attack was very low due to severe drought. The mild winter and sufficient precipitation in March and April gave good conditions for inoculum, but in May precipitation dropped to a severely low level. By the end of May the first signs of drought were measurable and prevented an attack of *Septoria* from developing further. Drought carried on through the summer, and only irrigated fields showed measurable symptoms of *Septoria*. As a result of the lack of precipitation, the level of attack on flag leaves was very low even in susceptible cultivars like Hereford and Cleveland.

Yellow rust (*Puccinia striiformis*). Cold weather around the time of field inoculation with yellow rust in susceptible cultivars delayed the development of yellow rust. Dry and warmer weather in May increased attacks in both Substance and Ambition. Substance, well known for its high susceptibility, developed a severe attack of yellow rust. Ambition is in general less susceptible and developed a slight to moderate attack. In trials inoculated with yellow rust the attack increased to a level of 28% at GS 69 leaf 2. Yellow rust is known for its ability to reduce yields, and attacks in 2018 showed significant yield responses to fungicide treatments.

Brown rust (*Puccinia triticina*). The mild winter 2017/2018 gave good conditions for inoculum to survive the winter. The warm and dry conditions gave good opportunities for brown rust to develop, and especially in susceptible cultivars such as Hereford were natural infections recorded at a moderate to severe level of 19% on the flag leaf GS 77.



A significant attack of brown rust developed late in the season, particularly in the cultivar Hereford.

Tan spot (*Drechslera tritici repentis*). An attack of tan spot developed poorly in April in fields with winter wheat as previous crop and minimal tillage. Due to dry weather in spring and all through summer, the attack of tan spot never developed significantly even in susceptible cultivars. Even trials carried out at a trial site that was pre-infected with infected straw showed only a very low level of attack, which limited options for efficacy evaluations. In trials with infected straw, the level of attack never increased above 25% at leaf 1 in the cultivar Sheriff at GS 69. The level of attack in the cultivar Torp was very low and increased only to a level of 5% on leaf 1 at GS 69.

Fusarium head blight (*Fusarium* spp.). Trials with Fusarium head blight as target were inoculated to ensure attack. Due to the dry weather conditions, attacks in inoculated field trials were very slight and gave poor opportunities for distinguishing differences between fungicides. Small plot trials established to assess cultivar susceptibility towards *Fusarium* were irrigated daily, which ensured better conditions for the disease to establish and develop. The level of attack in cultivar trials gave acceptable opportunities for distinguishing differences between cultivar susceptibility, and mycotoxins also developed significantly.

Eye spot (*Tapesia herpotrichoides*). Attacks of eye spot were assessed only in a few trials in which the level of attack was slight to moderate.

Triticale and rye

Yellow rust (*Puccinia striiformis*). A moderate attack of yellow rust developed in the triticale trials in 2018. The triticale trials were naturally infected and levels increased to 20% at GS 71-75 on leaf 2. The disease level gave good opportunities for distinguishing between the performances of the products.

Glume blotch (*Parastagonospora nodorum*). In this year's triticale trials the attack of glume blotch was recorded to be at a low level.

Brown rust (*Puccinia recondita*) appeared in rye and developed late in the season with a moderate attack of 13% on leaf 2. Despite the late incidence of attack, good opportunities for distinguishing the performances of the products were present. Brown rust is known to reduce yields, but due to severe drought and no irrigation of rye and triticale the yield responses were limited.

Powdery mildew (*Blumeria graminis secalis*). A significant attack of powdery mildew developed in triticale trials, giving good opportunities for distinguishing between the performances of the products. The disease attack increased to 12% at GS 69-75.

***Rhynchosporium* (*Rhynchosporium secalis*).** A moderate attack of *Rhynchosporium* developed in the rye trials in 2018. The disease level gave good opportunities for distinguishing between the performances of the products. The attack of *Rhynchosporium* in rye increased to 15-23% at GS 77.

Winter barley

Powdery mildew (*Blumeria graminis*). A minor attack of mildew developed in the cultivar Wootan during the 2018 trial period; due to a low level of attack, the opportunities for distinguishing between the performances of the products were limited.

Brown rust (*Puccinia hordei*). Attacks of brown rust developed in all trials and cultivars. Particularly the cultivars Wootan, Matros and Celtic developed severe attacks, which gave good opportunities for distinguishing the efficacy of different fungicides in 2018. The average attack of brown rust in this year's trial at Flakkebjerg reached a level of 21% at GS 71-75.

***Rhynchosporium* (*Rhynchosporium commune*).** A moderate to severe attack of *Rhynchosporium* developed in the cultivars Frigg and Wootan and a minor attack developed in Matros as well. In trials with *Rhynchosporium* the opportunities for distinguishing between the performances of the products were good. The average attack of *Rhynchosporium* reached a level of 17% at GS 69-75.

Net blotch (*Drechslera teres*). A moderate to severe attack of net blotch developed during the season in trials depending on cultivar. Celtic and Matros developed severe attacks, which gave good opportunities for distinguishing between the performances of the fungicides. In trials with net blotch the average attack in the susceptible cultivars reached a level on upper leafs of 21 % at GS 71-77.

Ramularia leaf spot (*Ramularia collo-cygni*). In contrary to 2017 only few trials in 2018 showed attack of Ramularia leaf spot. A few trials in the cultivars Celtic and Matros developed very late, and only a minor attack developed and gave limited opportunities for distinguishing between the performances of the fungicides. In the specific trials, the average attack of Ramularia leaf spot reached a level of 6% at GS 71-75.

Spring barley

Powdery mildew (*Blumeria graminis*). The attack in 2018 was minimal and limited to the cultivars Milford and Propino, which do not carry mlo resistance. In the trials both cultivars provided possibilities for ranking the performances of the product. The attack of powdery mildew reached a level of 2-13% at GS 59-71 (average of 4 trials: 5.6%).

Net blotch (*Drechslera teres*) appeared with minor or moderate attacks in some cultivars. In previous years the cultivar Chapeau had shown severe attacks of net blotch. In 2018 both Chapeau and Laurikka developed similar, minor to moderate attacks. In the trials both cultivars provided possibilities for ranking the performances of the product. Attacks of net blotch in Chapeau and Laurikka reached an average level of 4.7% on upper leaves at GS 71-77.

***Rhynchosporium* (*Rhynchosporium secalis*).** No attack of *Rhynchosporium* appeared in spring barley trials in 2018.

Brown rust (*Puccinia hordei*). All trials developed different levels of attack in 2018. High levels of attack were seen especially in the cultivars Chapeau and Milford, which gave good opportunities for distinguishing between the performances of the fungicides. The attack at Flakkebjerg reached levels varying between 4 and 40% at GS 71-77.

Ramularia leaf spot (*Ramularia collo-cygni*). No attack of *Ramularia* appeared in spring barley trials in 2018.

Yield increases in fungicide trials in cereals

The harvest 2018 was dry and warm, which ensured optimal harvest conditions. The yields in the trial varied depending on irrigation intensity. The average yield in winter wheat 2018 reached 95 hkg/ha. The winter wheat trials generally yielded well due to irrigation and typically in the range of 70-110 dt/ha, but drought spots varied across trials and very few trials showed significant increases of yield. Winter barley trials were not irrigated in the growing season 2018, and the winter barley wilted early due to lack of precipitation. Yields reached 60-80dt/ha. The spring barley suffered from the lack of precipitation even though most fields were irrigated two times during May and June. In spring barley the yield level was moderate, around 50-75 dt/ha.

Yield increases following fungicide treatments in wheat were close to non-existing (Table 1). Most trials did not respond to fungicide treatments at all. The only exception was trials with moderate attacks of *Septoria* or yellow rust. Even in these trials increases varied due to drought spots, which were present in most trials.

Yield responses in spring barley were limited, and very few trials gave positive yield responses. Standard treatments in spring barley at AU gave yield increases between 4 and 5 hkg/ha.

The general yield response was higher for winter barley. Severe attacks of rust and net blotch were the reason for increases. The standard treatments in the AU winter barley trials yielded an average of 8.4 hkg/ha.

Table 1. Yield increases (dt/ha) for control of diseases using fungicides in trials. The responses are picked from standard treatments typically using 2 treatments per season. The numbers in brackets give the number of trials behind the figures. Data originate from SEGES and AU-Flakkebjerg trials.

Year	Winter wheat	Spring barley	Winter barley
2005	6.4 (126)	5.4 (43)	4.6 (60)
2006	8.0 (106)	3.3 (63)	5.1 (58)
2007	8.5 (78)	7.2 (26)	8.9 (13)
2008	2.5 (172)	3.1 (29)	3.2 (36)
2009	6.3 (125)	5.1 (54)	6.3 (44)
2010	6.6 (149)	5.6 (32)	5.9 (34)
2011	7.8 (204)	3.9 (43)	4.3 (37)
2012	10.5 (182)	6.7 (38)	5.1 (32)
2013	10.3 (79)	5.2 (35)	5.5 (27)
2014	12.0 (82)	3.0 (19)	4.1 (18)
2015	10.9 (102)	9.1 (20)	7.3 (19)
2016	10.9 (93)	8.0 (29)	4.0 (21)
2017	15.0 (149)	10.4 (27)	11.9 (25)
2018	4.3 (45)	3.6 (16)	7.5 (14)

Maize

Eye spot (*Kabatielle zeae*). Despite the high amount of debris from maize present in the field from maize growing in previous years, only minor and insignificant attacks of eye spot developed in trials during the 2018 season. The trials were irrigated times in June, and the first attack on leaves around the cob was assessed in mid-August. Due to the lack of precipitation in general, the attack never increased during the summer and assessments gave limited opportunities to distinguish between the performances of the products. The attack never increased above 2%. The attack did not have a significant effect on yield parameters.

Northern leaf blight (*Setospharia turcica*). A moderate attack developed during August and September. Due to the drought, wilting happened early and limited the number of assessments. The level of attack gave minor opportunities to distinguish between the performances of the products. The attack increased to a level of 22.7% by mid-September.

Potato

Potato early blight (*Alternaria solani*)

The trials at Flakkebjerg were artificially inoculated on 14-20 June 2018 with autoclaved barley seeds inoculated with *A. solani* and *A. alternata*. Generally, the weather was characterised by fewer hours of leaf wetness during the months of June and July, which was unfavourable for the development of early blight. Thus after the onset of the disease on 13 July, the disease development was generally restricted during the months of July until the early weeks of August. The month of August and beyond was characterised by many rainy days, high humidity and temperatures favourable for the development of early blight, and these conditions resulted in a severe epidemic of early blight. By the end of September, the severity level of early blight in the untreated plots was 80-100%.

Attack of early blight (*Alternaria solani*) on potato leaf. (Photo: Hans Hansen).

Potato late blight (*Phytophthora infesta*ns)

The late blight trials were inoculated with a sporangial suspension of *Phytophthora infestans*. The first late blight attack on the leaves and stems of the potato crops was observed on 2 July at Flakkebjerg. However, the weather conditions subsequent to the onset of the first symptoms were characterised by high temperatures and low humidity. Therefore, the foliar lesions dried up quickly. In contrast to the foliar infection, the infection and sporulation on the stems continued to grow until 16 July when these stem attacks also began to dry up. Favourable conditions, that is many rainy days, occurred from 11-12 August, and this revived the development of late blight perhaps from sporangia that survived in the stems of the potato crops in the previous infection from the inoculation on 26 June. Accordingly, late blight was sporulating between the withered and green part of the stems from 13 August. The first airborne attack of late blight was observed in the trials from 21 August. The dry September was not conducive for tuber infections, and thus tuber attacks were limited (0-3%) in all the trials.

II Disease control in cereals

Lise Nistrup Jørgensen, Thies Marten Heick, Niels Matzen, Hans-Peter Madsen, Helene Saltoft Kristjansen, Sidsel Kirkegaard & Anders Almskou-Dahlgaard

Introduction

In this chapter, field trials in cereals carried out with fungicides in 2018 are described in brief and results are summarised. In graphs or tables are also included results from several years if the trial plan concerns several years. Included are main results on major diseases from both protocols with new fungicides and protocols in which products applied at different dose rates and timings are compared. Some of the trial results are used as a part of the Biological Assessment Dossier, which the companies have to prepare for new products or for re-evaluations of old products. Other parts of the results aim at solving questions related to optimised use of fungicides in common control situations for specific diseases.

Apart from the tables and figures providing main data, a few comments are given along with some concluding remarks.

Methods

All field trials with fungicides are carried out as GEP trials. Most of the trials are carried out as field trials at AU Flakkebjerg. But some trials are also sited in farmers' fields, at Jyndevad Experimental Station or near Hadsten in collaboration with a GEP trial unit at the advisory group LMO. Trials are carried out as block trials with randomised plots and 4 replicates. Plot size varies from 14 to 35 m^2, depending on the individual unit's equipment. The trials are sited in fields with different, moderately to highly susceptible cultivars, specifically chosen to increase the chances of disease development. Spraying is carried out using a self-propelled sprayer using atmospheric air pressure. Spraying is carried out using 150 or 200 l water per ha and a nozzle pressure of 1.7-2.2 bar.

Attacks of diseases in the trials are assessed at approximately 10-day intervals during the season. Per cent leaf area attacked by the individual diseases is assessed on specific leaf layers in accordance with EPPO guideline 1/26 (4) for foliar and ear diseases in cereals. At the individual assessments, the leaf layer that provides the best differentiation of the performances of the fungicides is chosen. In most cases this is the 2 upper leaves. In this publication only some assessments are included – mainly the ones giving the best differentiation of the efficacy of the products.

Nearly all trials are carried through to harvest, and yield is adjusted to 15% moisture content. Quality parameters like specific weight, % protein, % starch and % gluten content are measured using NIT instruments (Foss), and thousand grain weight is calculated based on 250 grains counted. In spring barley, which can potentially be used for malting grain, size fractions are also measured. For each trial, LSD_{95} values or specific letters are included. Treatments with different letters are significantly different, using the Student-Newman-Keuls model.

When a net yield is calculated, it is converted to hkg/ha based on deducting the cost of used chemicals and the cost of driving. The cost of driving has been set at DKK 70 and the cost of chemicals extracted from the database at SEGES. The grain price used is 140 DKK/hkg (= dt).

1. Control of diseases in winter wheat

Inatreq (fenpicoxamid)

Inatreq (fenpicoxamid) introduces a new mode of action for control of *Septoria* attack in winter wheat. The product is expected to reach the market in 2020. Inatreq has been tested as a solo product (GF-3308) and in mixture with prothioconazole (GF-3307). The product has in wheat trials provided good control when applied at different timings. Dose rates between 1.0 l and 2.0 l per ha have provided robust control and in many cases superior control and yield responses compared with current Danish standards. The product has shown both preventive and curative control.

Results with GF-3307 (50 g fenpicoxamid + 100 g prothioconazole per litre)
Inatreq (fenpicoxamid) belongs to a new group of fungicides, which have not previously been authorised for disease control in cereals. The product targets the respiration in the mithochondrea of the fungi and belongs to the QoIs. The product was discovered by Dow AgroSciences and should be available to cereal growers in 2020. The new active is derived from a natural compound, UK 2A, which is produced by fermentation of an actinomycete (*Streptomyces* spp.), which then undergoes a minor alternation to stabilise the product. Inatreq shows no cross-resistance to existing cereal fungicides, including azoles, strobilurins and SDHIs. However, as the active in Inatreq is a target site inhibitor, the product should only be used in combination with other actives to minimise the risk of resistance development.

Inatreq has been tested in early development trials in Denmark and these trials have consistently confirmed very good control of Septoria tritici blotch (STB) under both preventive and curative conditions. Inatreq is a systemic fungicide and has shown good residual effect on STB and - depending on the dose used - given 4-8 weeks control. Using a higher dose might point in the direction of using fewer treatments per season. At the time of writing it is not known which dose will be authorised, but dose rates from 0.5 to 2.0 l were typically tested in trials.

Going back 5 years, mixing fenpicoxamid with prothioconazole was seen as a good idea as this azole provided good control on most cereal diseases and was also considered as the azole with the most robust tox- and eco-tox profile. In more recent years the efficacy on STB from prothioconazole has been reduced significantly in many regions due to resistance development, and today prothioconazole is seen as a less ideal partner for fenpicoxamid when it comes to control of STB. Anyhow, when it comes to other diseases such as control of yellow rust, tan spot and powdery mildew, prothioconazole helps significantly to broaden the profile of GF-3307, compared to using fenpicoxamid alone.

1.5 l Inatreq (GF-3308)1 July 2017 (17320-1) Untreated

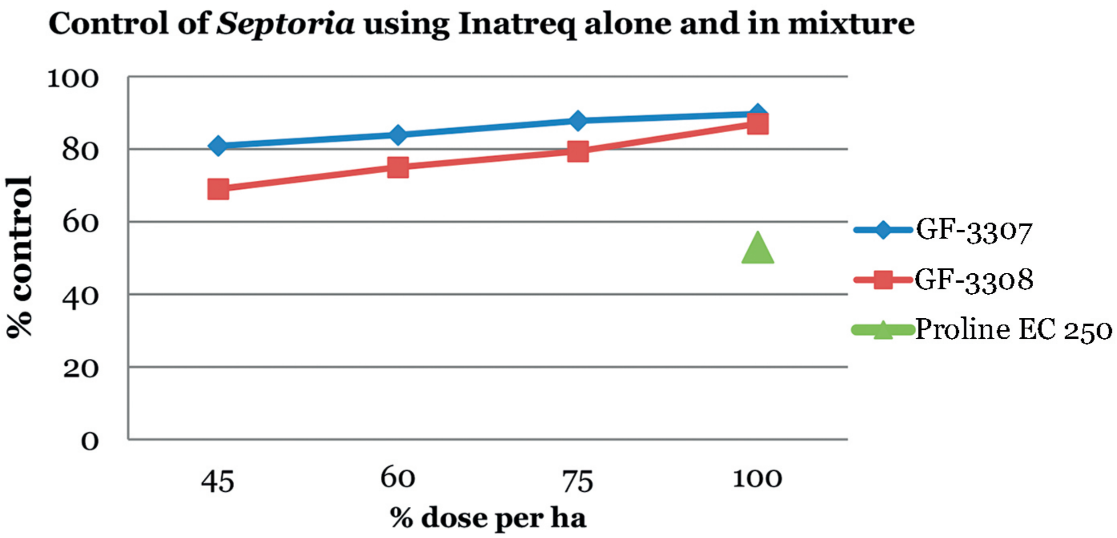
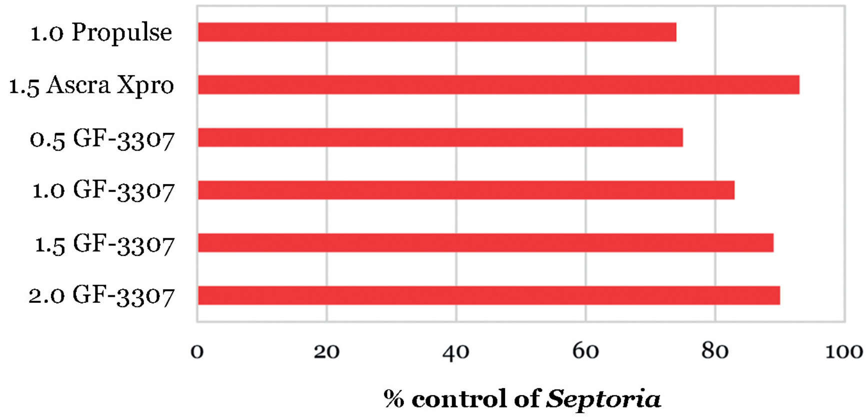


Figure 1. Control of *Septoria* using 1 treatment at GS 37-39. Comparing 4 rates of GF-3307 and GF-3308 with Proline EC 250. Average of 4 trials 2016 (16318). Assessed on the 2[nd] leaf with 30% attack of STB in untreated. Dose varies from 0.9 to 2.0 l/ha.

Specific dose response trials with fenpicoxamid (GF-3308) and fenpicoxamid + prothioconazole (GF-3307) were carried out and results are shown in Figure 1. Similarly, results from 2 trials in 2017 in which GF-3307 was compared with Propulse SE 250 and Ascra Xpro showed a clear drop in efficacy when the dose was lowered to 1.0 l/ha or less (Figure 2). In 2017 further trials were carried out, which also showed a good robustness using GF-3307 from 2.0 to 1.0 l/ha. Dose rates below 1.0 l/ha showed inferior control and yield responses (Figure 2). The best yield responses were obtained from GF-3307 applied at GS 37-39 (Table 3).



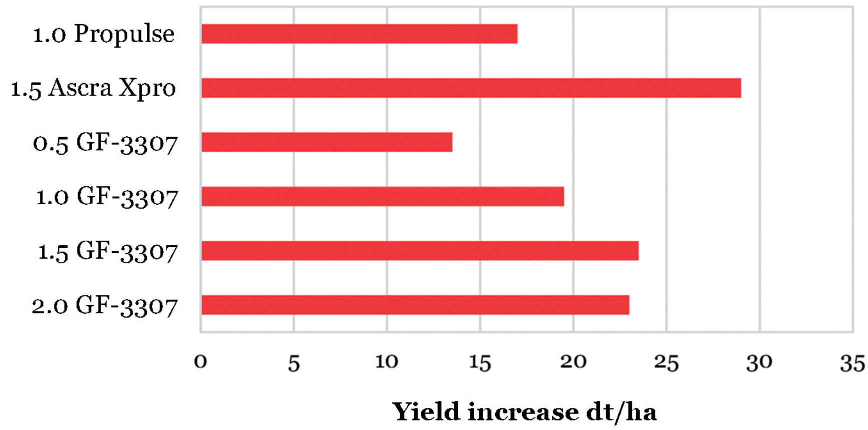
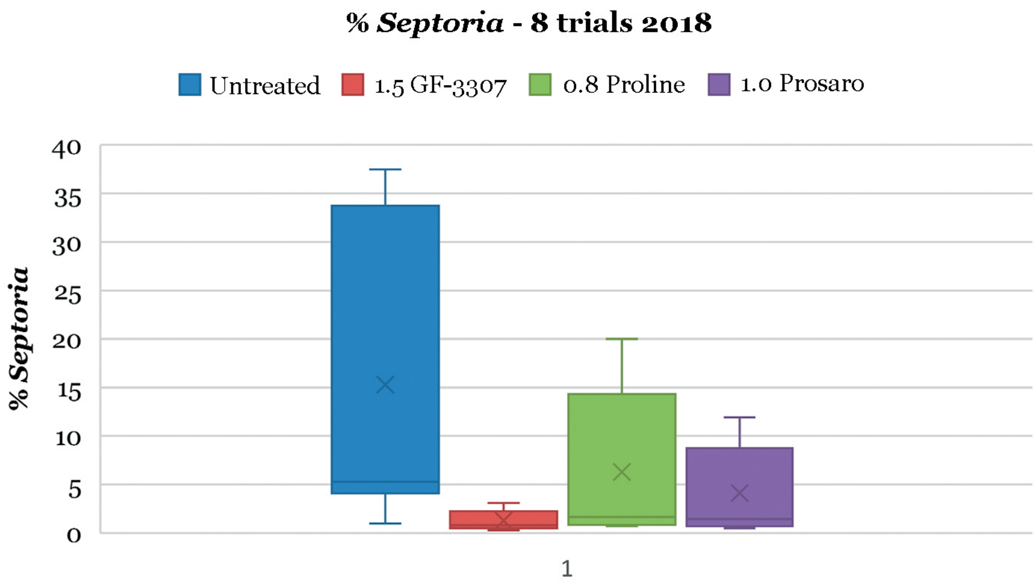


Figure 2. Control of *Septoria* and yield response using 1 treatment at GS 37-39. Comparing 4 rates of GF-3307 with Ascra Xpro and Propulse SE 250. Average of 2 trials 2017 (17315).

Trials in 2018 suffered from dry and hot weather but did still develop significant attacks of STB (Figure 3, Table 1). When the different reference products were compared with GF-3307, it was clear that the performance of the product was superior to both Proline EC 250 and Prosaro EC 250 but in line with the best SDHI solutions such as Imtrex and Librax. Due to drought, the trial results did not provide any significant yield differences.

Table 1. Per cent attack of *Septoria* in different trials carried out in 2018, in which Proline EC 250, Prosaro EC 250 and Imtrex/Librax were used as reference products. Assessment were carried out on the 2nd leaf and typically between GS 65 and GS 75. In some trials Imtrex was used instead of Librax.

Treatments applied at GS 37-39, l/ha	% *Septoria*	% *Septoria*	% *Septoria*
Untreated	14.3	15.3	16.9
GF-3307 1.5	2.7	1.3	3.7
Proline EC 250 0.8	7.1	6.3	8.4
Prosaro EC 250 1.0	-	4.1	-
Librax/Imtrex 1.2/2.0	-	-	2.7
No. of trials	13	8	8



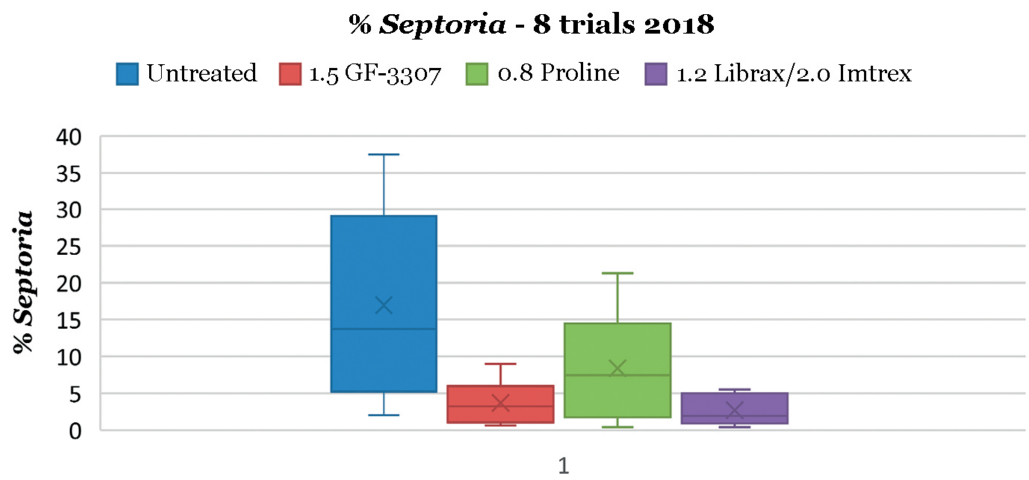


Figure 3. Per cent Septoria tritici blotch in winter wheat. Data are extracted from different development trials, which all were treated at GS 37-39.

Strategy trials in 2017 generally showed good control of STB when using GF-3307. Two treatments using GF-3307 applied in a split ear treatment provided the best control. Similar control was obtained from 2 x 1.5 l GF-3307 and 2 x 1.0 l GF-3307, while 2 x 0.5 l GF-3307 showed less good control (Table 2). If treatment was only carried out at GS 59, the overall efficacy was less good and yields were also lower.

In one trial the products were tested for control of tan spot (DTR). Again, double treatments or the higher rates of GF-3307 provided best control, but also solo treatments with Ascra Xpro and 2.0 l GF-3307 gave good control. The trial did not provide clear and significant differences between treatments.

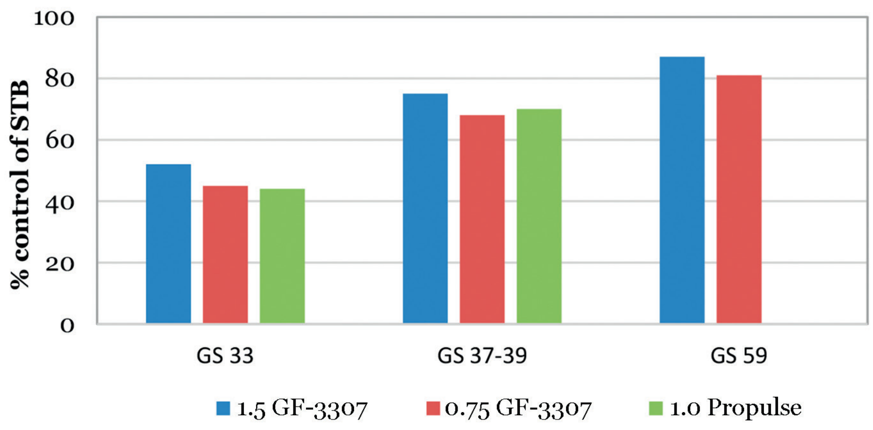
The trials from 2017 and 2018 tested different timings and doses. Double treatments used at either GS 33 + GS 37-39 or GS 37-39 + GS 59 performed better than single treatments. 1.5 l of GF-3307 performed better than 0.75 at all timings (Figure 4; Table 3). The trials from 2018 did not add much new information as the trials suffered from a minor attack of *Septoria* and drought, which made the results less reliable (Tables 4-5). The data from trial 18353 (Figure 5; Table 5) did, however, still show a clear effect from GF-3307 on the lower leaves.

Table 2. Effect of different fungicides on *Septoria* and yield responses following 1-2 applications in wheat. 2 trials with *Septoria* and 1 trial with DTR (17316).

Treatments, l/ha			% *Septoria*		% DTR	Yield and increase hkg/ha 2017	
GS 33	GS 37-39	GS 59	GS 75 L 1	GS 73 L 2	GS 75 L1	*Septoria* trials	DTR trial
1.	Untreated		34.1	63.8	43.8	80.0	64.0
2.	Viverda + Ultimate S 0.6 + 0.6		14.2	45.7	20.0	11.0	7.0
3.		GF-3307 1.5	8.8	33.8	21.3	11.0	4.0
4.	Viverda + Ultimate S 0.6 + 0.6	GF-3307 1.5	4.9	21.3	16.8	17.0	12.0
5.	Viverda + Ultimate S 0.6 + 0.6	GF-3307 1.0	5.5	21.9	25.0	15.5	12.0
6.	Viverda + Ultimate S 0.6 + 0.6	GF-3307 0.75	5.7	23.8	26.8	13.5	0.8
7.	Viverda + Ultimate S 0.6 + 0.6	GF-3307 0.5	5.0	25.7	Mistake	12.0	-
8.	GF-3307 1.5	GF-3307 1.5	4.0	18.7	17.5	18.0	12.0
9.	Viverda + Ultimate S 0.6 + 0.6	Propulse SE 250 0.4	9.8	35.7	25.0	9.5	5.0
10.		Propulse SE 250 1.0	15.6	43.8	25.0	6.5	5.0
11.		Ascra Xpro 1.5	14.9	40.0	17.3	14.0	9.0
12.		Proline EC 250 0.8	17.4	46.9	26.3	6.0	4.0
13.		GF-3307 2.0	9.9	37.5	18.8	13.5	6.0
14.	GF-3307 1.0	GF-3307 1.0	3.7	18.8	NT	18.5	-
15.	GF-3307 0.5	GF-3307 0.5	4.4	25.7	NT	15.0	-
No. of trials			2	2	1	2	1
LSD_{95} (excl. untr.)						4.3	9.5

Table 3. Effects of different fungicides on *Septoria* and yield responses following 1-3 applications in wheat. 2 trials (17317).

Treatments, l/ha			% *Septoria*		Yield and increase hkg/ha 2017
GS 33	GS 37-39	GS 59	GS 75 L 1	GS 71 L 2	
1. GF-3307 1.5			16.9	10.5	8.0
2.	GF-3307 1.5		8.8	5.6	14.0
3.		GF-3307 1.5	4.7	11.0	13.0
4. GF-3307 1.5	GF-3307 1.5		5.2	2.8	15.5
5. GF-3307 1.5		GF-3307 1.5	2.7	4.9	16.5
6.	GF-3307 1.5	GF-3307 1.5	2.9	4.2	15.0
7. GF-3307 0.75			19.2	15.7	7.0
8.	GF-3307 0.75		11.3	8.7	10.0
9.		GF-3307 0.75	6.5	12.4	9.5
10. GF-3307 0.75	GF-3307 0.75		9.3	6.4	13.0
11. GF-3307 0.75		GF-3307 0.75	3.9	7.4	14.5
12.	GF-3307 0.75	GF-3307 0.75	3.7	6.2	14.0
13. Propulse SE 250 1.0			19.8	15.8	6.5
14.	Propulse SE 250 1.0		10.4	7.4	13.5
15.	Propulse SE 250 0.5	Propulse SE 250 0.5	9.6	9.0	12.5
16. Untreated			35.1	26.5	85.5
No. of trials			2	2	2
LSD_{95} (excl. untr.)					3.5



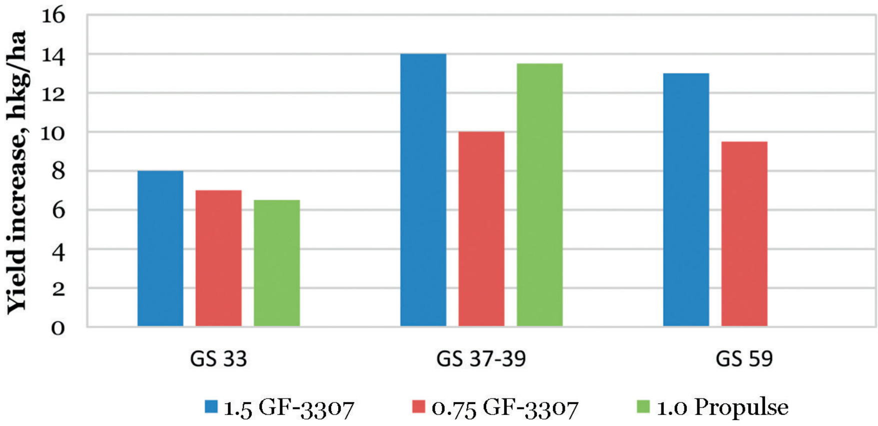


Figure 4. Per cent control of Septoria tritici blotch and yield responses (LSD 3.5) in winter wheat using different timings (17317).

Table 4. Application timings. Effects on *Septoria* and yield responses following 1-2 treatments in wheat (18324).

Treatments, l/ha				% *Septoria* GS 75 L3	% green leaf area GS 77 L2	Yield and increase hkg/ha	
GS 33	GS 37-39	GS 45-51	GS 55-61			Increase	TGW (g)
1.	Untreated			10.5	32.5	84.0	30.2
2.	GF-3307 0.75		GF-3307 0.75	3.5	42.5	5.9	32.4
3.		GF-3307 0.75		4.0	47.5	4.0	33.9
4.		GF-3307 1.0		3.0	35.0	10.3	32.9
5.		GF-3307 1.25		4.5	47.5	1.6	31.6
6.		GF-3307 1.38		2.3	53.8	7.6	33.8
7.	Propulse 0.5		Propulse 0.5	2.3	40.0	11.6	32.0
8.		Propulse 1.0		3.8	45.0	2.0	32.7
9.			GF-3307 1.38	2.8	40.0	3.9	32.0
10. GF-3307 0.75		GF-3307 0.75		2.8	42.5	-1.6	32.3
No. of trials				1	1	1	1
LSD_{95} (excl. untr.)				3.35	NS	NS	NS

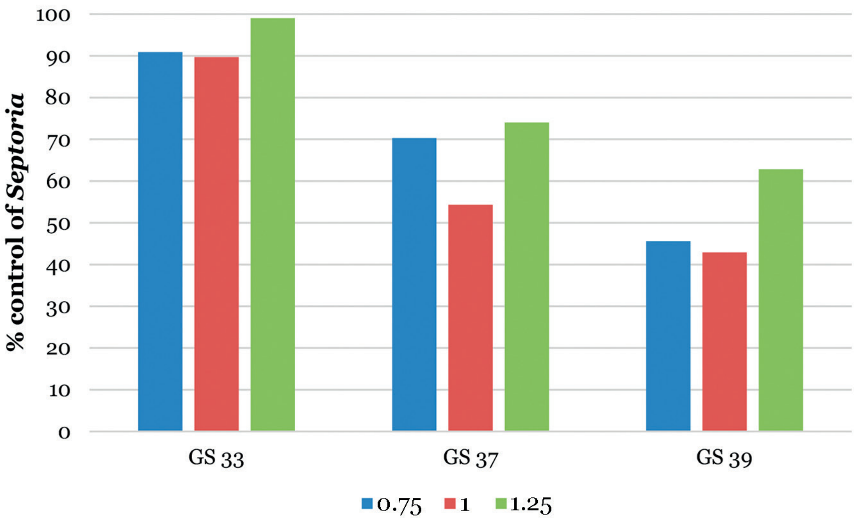


Figure 5. Per cent control of Septoria tritici blotch in winter wheat on the third leaf using different timings and dose rates of GF-3307 (18353).

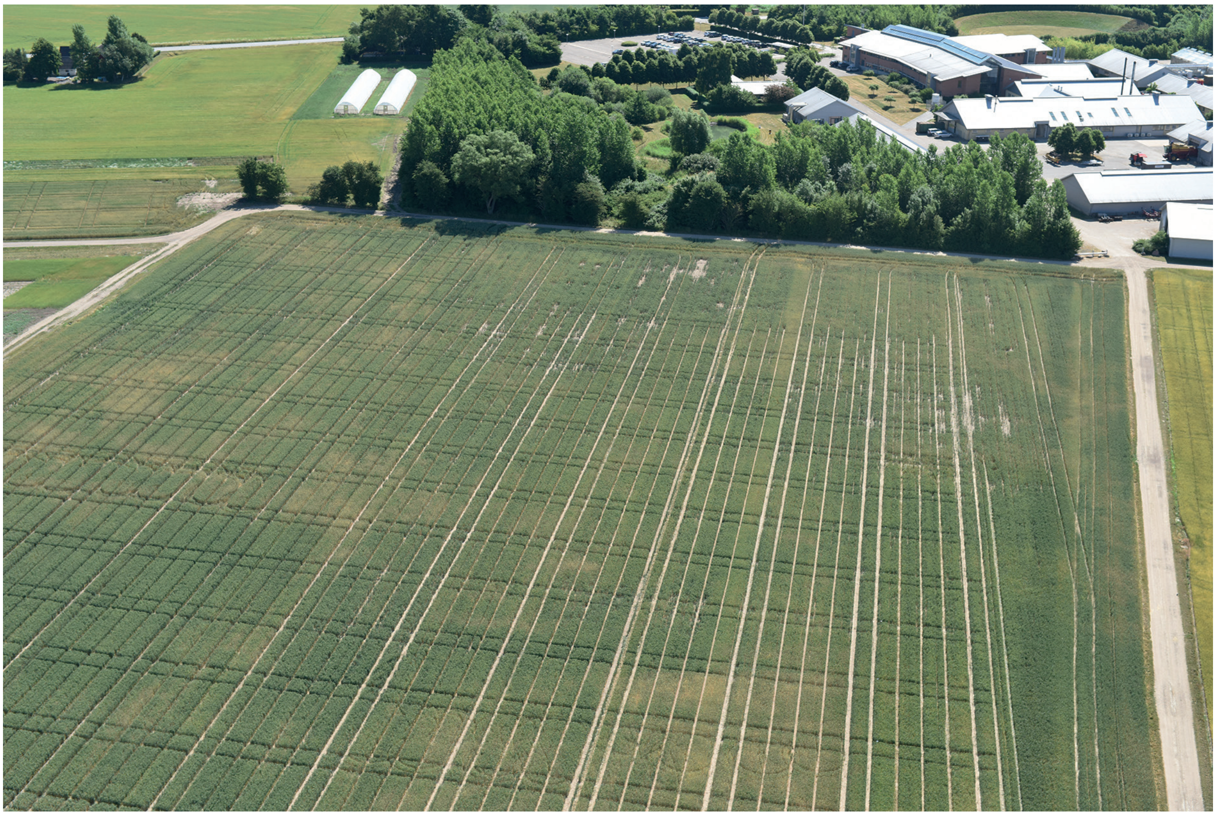


Table 5. Application timings. Effects on *Septoria*, brown rust and yield responses following 1-3 treatments in wheat (18353).

Treatments, l/ha						% *Septoria* GS 75 L3	% brown rust GS 83 L1-2	% green leaf area GS 83 L1	Yield and increase hkg/ha
GS 30	GS 33	GS 37	GS 39	GS 45	GS 51-55				
1. Untreated						43.8	17.6	65.0	90.0
2.	GF-3307 0.75				Propulse 0.4 + Comet Pro 0.3	4.0	4.3	86.3	12.2
3.		GF-3307 0.75			Propulse 0.4 + Comet Pro 0.3	13.0	3.1	88.8	15.4
4.			GF-3307 0.75		Propulse 0.4 + Comet Pro 0.3	22.5	1.3	90.0	9.2
5. Prosaro 0.3			GF-3307 0.75		Propulse 0.4 + Comet Pro 0.3	20.0	2.5	88.8	6.9
6. Prosaro 0.3				GF-3307 0.75 + Comet Pro 0.3		16.3	0.1	93.3	10.0
7.	GF-3307 1.0				Propulse 0.4 + Comet Pro 0.3	4.5	3.5	88.8	14.9
8.		GF-3307 1.0			Propulse 0.4 + Comet Pro 0.3	20.0	4.0	86.3	11.5
9.			GF-3307 1.0		Propulse 0.4 + Comet Pro 0.3	25.0	2.0	89.6	7.6
10. Prosaro 0.3			GF-3307 1.0		Propulse 0.4 + Comet Pro 0.3	18.8	0.9	91.3	15.0
11. Prosaro 0.3				GF-3307 1.0 + Comet Pro 0.3		10.0	0.1	92.5	16.3
12.	GF-3307 1.25				Propulse 0.4 + Comet Pro 0.3	3.3	5.3	82.5	15.4
13.		GF-3307 1.25			Propulse 0.4 + Comet Pro 0.3	11.3	4.4	82.5	13.4
14.			GF-3307 1.25		Propulse 0.4 + Comet Pro 0.3	16.3	0.3	92.5	16.5
15. Prosaro 0.3			GF-3307 1.25		Propulse 0.4 + Comet Pro 0.3	20.0	0.9	93.3	13.9
16. Prosaro 0.3				GF-3307 1.25 + Comet Pro 0.3		16.7	0.1	92.5	8.6
No. of trials						1	1	1	1
LSD_{95} (excl. untr.)						11.77	8.68	NS	NS

Revysol (mefentrifluconazole)

Revysol (mefentrifluconazole) is a new azole from BASF, which has shown good control of particularly *Septoria* attack in winter wheat. The product is expected to reach the market in 2020. Revysol has been tested as a solo product and also in combination with other actives. Dose rates between 0.75 and 1.5 l per ha have provided robust control and generally superior control and yield responses compared with other tested azoles.

Revysol has been tested at AU-Flakkebjerg for several years and shown very good control of particularly Septoria tritici blotch. The product is developed by BASF and is an innovative azole fungicide, which provides fast-acting, long-lasting and reliable performance to combat diseases on a broad range of crops. The product is an azole but has its own group and has a molecular structure that provides a more flexible docking in the target site. The product is not yet authorised but is expected to be on the European market by 2020.

Trials in both 2017 and 2018 showed high levels of *Septoria* control as described in Figures 6-7 and Tables 6-7. The product was tested both as a solo treatment applied at T2 and as a double treatment at T1 and T2. Proline EC 250 was used for comparison. A very clear link between green leaf area and yield responses was seen in the trials (Figure 8).

Table 6. Average *Septoria* and yield responses from treatments in winter wheat. 2 trials in 2017 (17303).

Treatments, l/ha		% *Septoria*				Yield and increase hkg/ha	TGW (g)
GS 32 (A)	GS 39-45 (B)	GS 45-51 L 4	GS 75-77 L 2	GS 75-77 L1	GLA L 1		
1. Untreated	Untreated	20.3	70.0	51.3	0.6	79.7	32.9
2. Proline 0.4	Proline 0.4	10.5	45.6	30.6	4.0	5.7	36.2
3. Proline 0.8	Proline 0.8	7.9	37.5	29.6	16.2	8.3	36.3
4. Revysol 0.75	Revysol 0.75	1.0	8.9	2.0	60.6	20.6	37.3
5. Revysol 1.5	Revysol 1.5	0.5	5.0	0.7	74.4	23.0	39.7
6.	Proline 0.8	18.2	16.5	32.3	6.9	6.0	33.8
7	Revysol 1.5	18.6	8.9	9.4	80.6	22.0	37.1
No. of trials		2	2	2	2	2	2
LSD_{95}						5.1	1.0

Table 7. Average *Septoria* and yield responses from treatments in winter wheat. 1 trial in 2018 (18346).

Treatments, l/ha		% *Septoria*				Yield and increase hkg/ha
GS 32 (A)	GS 49-55 (B)	GS 61 L 3	GS 69 L 3	GS 73 L2	GLA L 2	
1. Untreated	Untreated	11.8	33.8	31.3	45.0	95.9
2. Proline 0.4	Proline 0.4	9.0	20.0	26.3	50.0	3.30
3. Proline 0.8	Proline 0.8	4.3	16.3	18.8	50.0	3.30
4. Revysol 0.75	Revysol 0.75	0.3	0.5	3.5	62.5	8.20
5. Revysol 1.5	Revysol 1.5	0.1	0.1	2.0	70.0	11.30
6.	Proline 0.8	6.8	20.0	22.5	53.3	6.50
7	Revysol 1.5	5.0	16.5	5.0	56.7	9.40
No. of trials		1	1	1	1	1
LSD_{95}		5.30	22.90	9.47	NS	8.2

The trials from both 2017 and 2018 showed a very superior control from Revysol for control of *Septoria* compared with Proline EC 250. The yield responses in 2017 were significant for all treatments, while this was not the case for 2018 when drought stressed the plants and gave very uneven yield data.

Untreated.

2 x 0.75 l/ha Revysol.

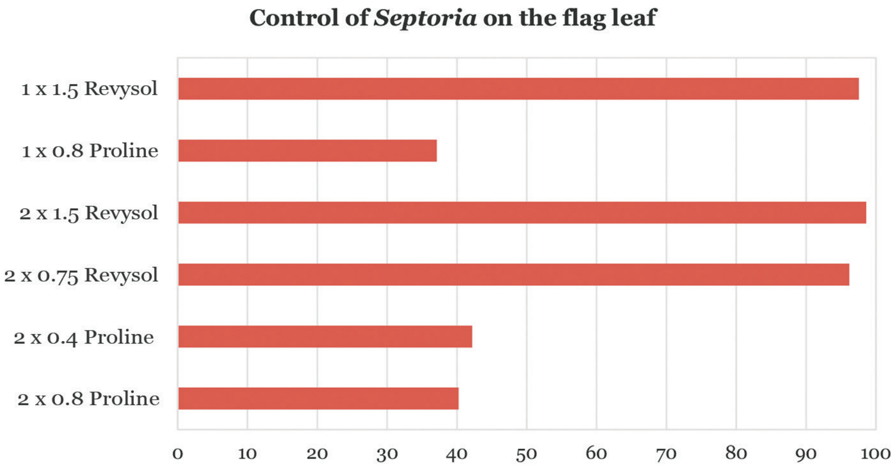


Figure 6. Per cent control of *Septoria* in 2 trials from 2017 (17303). Assessed at GS 75 on the flag leaf.

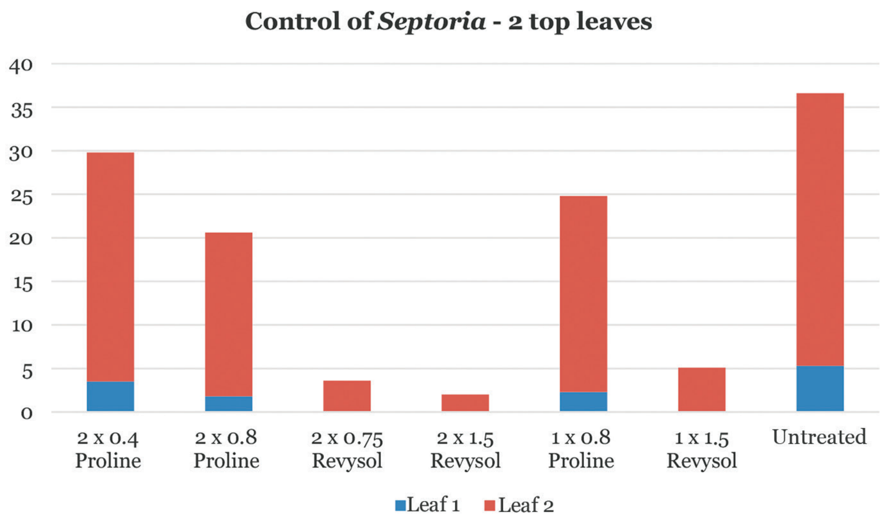


Figure 7. Per cent attack of *Septoria* on the flag leaf and 2nd leaf assessed at one trial in 2018 (18346-1).

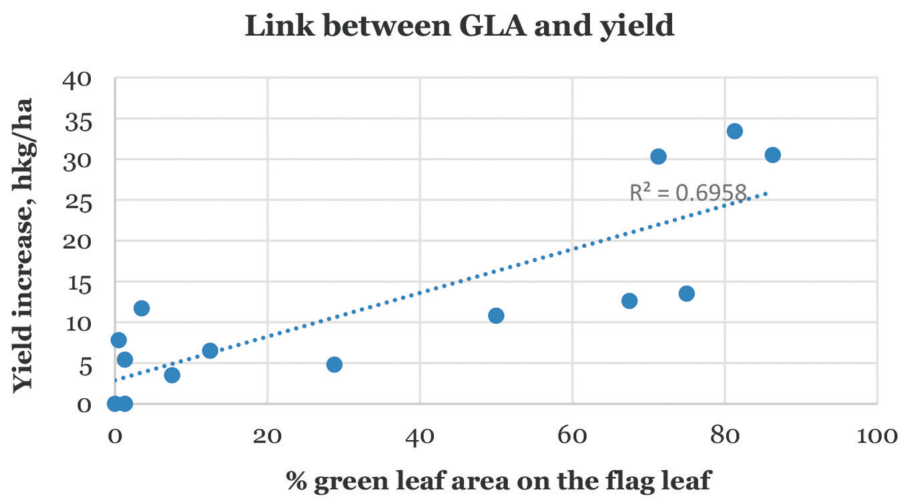


Figure 8. Link between % green leaf area on the flag leaf and yield increases (17303).

Revysol was also tested in several other trial plans, and results are shown in Tables 8 and 13. In these trials data showed that Revysol clearly outperformed other azoles. In the trial plan that is carried out as part of the EuroWheat project the trials showed superior control from products containing Revysol.

In a greenhouse trial carried out in 2018 Revysol was tested for control of glume blotch (*Stagonospora nodorum*) (Figure 9). Plants were grown and inoculated with spores and mycelium and sprayed at two different timings, one day before inoculation (preventive) and 7 days after inoculation (curative). The trial showed good control of S. nodorum from Revysol, Ascra Xpro and BAS 751 (Revysol + pyraclostrobin), while Proline EC 250 was inferior in its control. This drop in efficacy was most pronounced at the late timing and the lower rate. For the other products only minor differences were assessed between doses and timings.

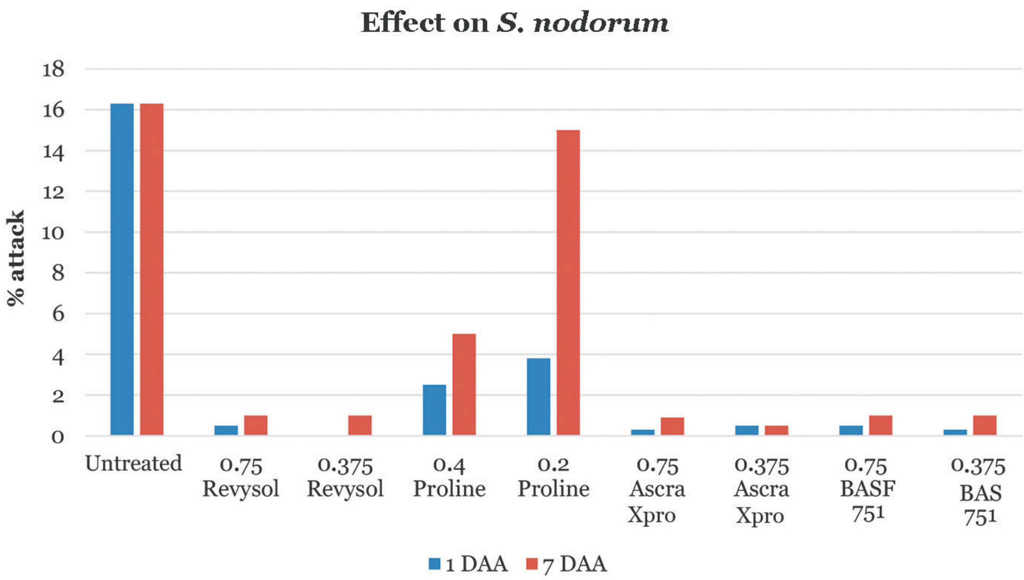


Figure 9. Per cent attack of *Stagonospora nodorum* in a greenhouse trial with applications 1 day before inoculation and 7 days after inoculation.

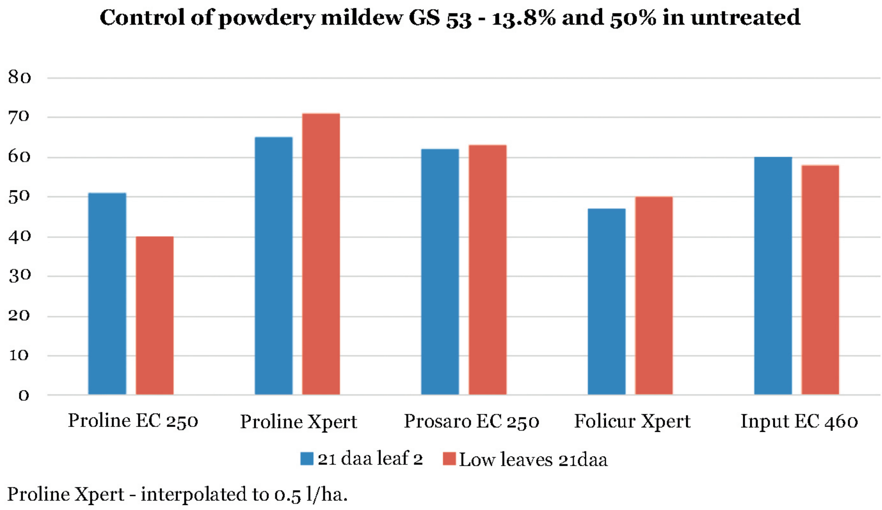
Control of powdery mildew (*Blumeria graminis*)

Denmark has only few specific fungicides for control of powdery mildew. In 2018 Talius got a full registration for control of powdery mildew in cereals, which was a major step forward as this product is very effective. Flexity only performs moderately, in line with or poorer than azole solutions. Input EC 460, which contains spiroxamine and prothioconazole, performed in line with azole solutions (Prosaro EC 250). Several of the cultivars grown (Benchmark, Sheriff, Pistoria) provided good resistance to mildew, while for instance Torp showed high susceptibility.

Several trials were carried out at Jyndevad Experimental Station, which is located on sandy soil in Jutland close to the German border and known for being a good site for investigation of mildew efficacy. The cultivar Torp was used in the trials.

Talius (proquinazid) has now got a full registration and is seen to provide good control of powdery mildew. No new trials were carried out with Talius in 2018.

Only few of the trials are open for publication. Azoles like tebuconazole and prothioconazole have over the years been seen to provide good control, if used at an early timing, but if an attack is very severe, azoles have proved to be insufficient. One trial from 2018 showed rather similar control from different formulations of prothioconazole and tebuconazole as well as from spiroxamine mixed with prothioconazole (Figure 10).



Active, l/ha	0.4 Proline EC 250	0.5 Proline Xpert	0.5 Prosaro EC 250	0.5 Folicur Xpert	0.5 Input EC 460
Prothioconazole	100	80	62.5	40	80
Tebuconazole		40	62.5	80	
Spiroxamine					150

Figure 10. Per cent control of powdery mildew in winter wheat in a trial with treatments applied at GS 31-32. The trial tested half rates of the different combination products, which at the tested rate contain the amounts given above. Proline Xpert was interpolated to reach 0.5 l/ha.

The situation at Jyndevad is regarded as a worst-case scenario for control of mildew, and it is expected that lower rates will be sufficient in fields with more moderate attacks. The crop at Jyndevad clearly suffered from severe attacks of powdery mildew. Significant yield responses were achieved from control of powdery mildew in 2018, when the trials were irrigated 8 times to keep the crop active - despite the severe drought.

Control of *Septoria* (*Zymoseptoria tritici*)

Septoria attack in 2018 was very low and insignificant due to a dry and hot summer. Useable *Septoria* data were in 2018 mainly collected on the 2nd and 3rd leaf. Almost no attack was seen on flag leaves. In line with data from the two previous seasons, the azoles prothioconazole and epoxiconazole again showed a reduced control. Mixtures with azoles showed better efficacy than single azoles. SDHIs generally showed better control than azoles used as solo products.

Comparison of azoles (18329)
Two trials testing different azoles were carried out in the cultivars KWS Cleveland at AU Flakkebjerg and Hereford at Horsens. The trials included two treatments using 2 half rates applied at GS 33 and 45-51. Only the trial at Flakkebjerg could be used for this year's assessment due to drought. The trial at Flakkebjerg developed a moderate attack on the 2nd and 3rd leaves which showed moderate control from the old azoles and mixtures of azoles (Table 8). The ranking in efficacy is shown in Figure 11. The new triazole, Revyzol, was included in the testing in 2017 and again in 2018. In both seasons this product showed outstanding control (approx. 90%) compared with the old single azoles as well as the azole mixtures. Single azoles gave between 25 and 50% control. The better of the azole mixtures provided on average 60% control.   In the 2018 season epoxiconazole performed slightly better than prothioconazole at the Flakkebjerg site. Generally both epoxiconazole and prothioconazole are known to be significantly influenced by the changes in the CYP51 mutation profile.

Data from all azoles across several years have shown a clear drop in efficacy from all azoles. Compared with previous years the last four seasons especially have shown a reduced control from epoxiconazole and prothioconazole. Summarised across years, the trials represent results from two sites - Flakkebjerg and LMO (Horsens/Hadsten) - although the data from 2018 only represent the Flakkebjerg trial. (Figure 12; Table 9).

Looking at the performance of azoles during a longer time spell, the drop in performance began in 2014, was less pronounced in 2015 but continued in 2016 and 2018 (Figure 12; Table 9). Some of the yearly variation can be linked to the levels of attack, but as discussed in chapter IV the *Septoria* populations have changed and do now include many more mutations than previously. The mutations are known to influence the sensitivity to azoles in general but are also seen to influence specific azoles differently. The drop in efficacy from tebuconazole has been known since about 2000. The drop in performance from tebuconazole used alone has changed since 2017 when tebuconazole was seen as the only azole not dropping further; in fact, this product gained slightly better efficacy, which is seen as linked to higher proportions of D134G and V136A. In both 2017 and 2018 it was seen that the mixtures prothioconazole + tebuconazole and difenoconazole + propiconazole performed best as the two actives are seen to support each other when it comes to controlling the different strains with different mutations.

Table 8. Effects of azoles on *Septoria* and yield responses following 2 applications in wheat. 1 trial (18329).

Treatments, l/ha		% *Septoria*		Yield and increase hkg/ha	Net yield hkg/ha
GS 33	GS 51-55	GS 75 L2	GS 77 L2		
1. Rubric 0.5	Rubric 0.5	5.63	10.75	-3.2	-6.79
2. Proline EC 250 0.4	Proline EC 250 0.4	8.13	11.88	0.6	-3.05
3. Juventus 90 0.5	Juventus 90 0.5	7.50	10.75	3.3	0.78
4. Bumper 25 EC 0.25	Bumper 25 EC 0.25	10.63	11.75	1.4	-0.27
5. Folicur EW 250 0.5	Folicur EW 250 0.5	3.38	3.25	7.4	4.74
6. Proline EC 250 0.4	Armure 0.4	4.00	4.88	0.5	-3.01
7. Prosaro EC 250 0.5	Prosaro EC 250 0.5	2.75	1.25	3.7	0.36
8. Proline EC 250 0.4	Amistar Gold 0.5	2.63	6.88	5.0	1.45
9. Revysol 0.75	Revysol 0.75	0.00	0.18	7.7	-
10. Untreated	Untreated	11.25	28.75	103.8	-
No. of trials		1	1	1	1
LSD_{95}		3.81	9.64	6.0	-

Table 9. Effect of azoles on *Septoria* and yield responses following 2 applications in wheat. 9 trials from 5 seasons (14329, 15329, 16329, 17329, 18329).

Treatments, l/ha		% *Septoria*				
GS 33	GS 51-55	GS 73-75 L1 2014	GS 73-77 L1 2015	GS 73-77 L1 2016	GS 73-77 L1 2017	GS 77 L1 2018
1. Rubric 0.5	Rubric 0.5	9.5	13.3	26.3	10.0	1.13
2. Proline EC 250 0.4	Proline EC 250 0.4	12.3	4.1	32.5	12.5	1.15
3. Juventus 90 0.5	Juventus 90 0.5	10.8	13.1	34.4	12.0	1.03
4. Bumper 25 EC 0.25	Bumper 25 EC 0.25	12.3	22.8	40.7	16.6	1.53
5. Folicur EW 250 0.5	Folicur EW 250 0.5	14.3	24.3	42.1	9.7	0.18
6. Proline EC 250 0.4	Armure 0.4	10.0	6.3	33.2	8.2	0.63
7. Prosaro EC 250 0.5	Prosaro EC 250 0.5	9.5	8.5	26.9	8.2	0.03
8. Proline EC 250 0.4	Amistar Gold	-	-	-	-	0.88
9. Untreated	Untreated	25.0	41.2	54.4	21.2	6.25
No. of trials		2	2	2	2	1

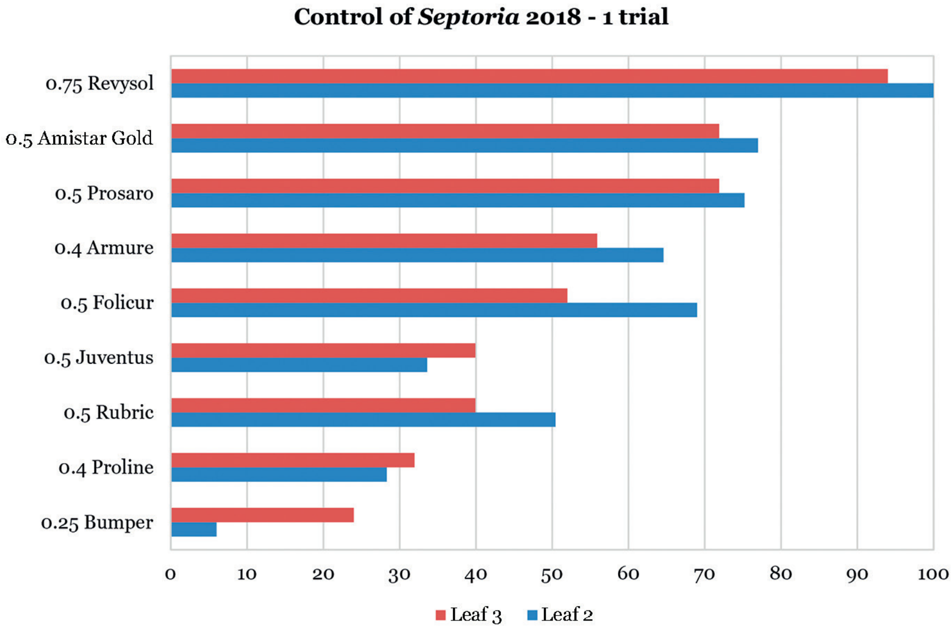


Figure 11. Per cent control of *Septoria* using 2 half rates of different azoles. Average of 2 applications at GS 33-37 and 51-55. Untreated with 11% *Septoria* attack on the 2nd leaf and 31% on the 3rd leaf. The data originate from one trial in 2018 (18329-1).

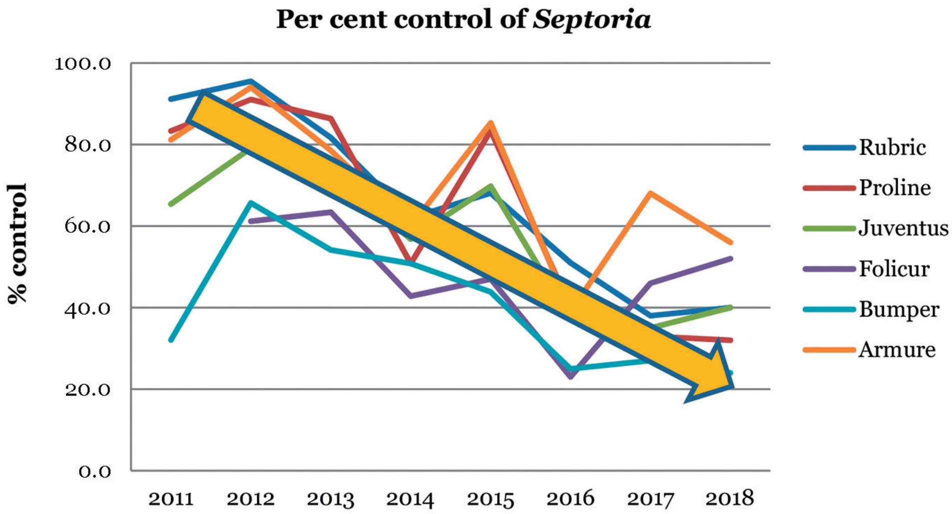


Figure 12. Per cent control of *Septoria* using 2 half rates of different triazoles. Average of 2 applications at GS 33-37 and 51-55. Development of efficacy across years.

Comparison of available solutions for ear treatments (18325)

In line with trials from previous years, treatments with different fungicides were tested when applied during heading (GS 51-55) (Table 10). A cover spray was applied at GS 32 using Prosaro EC 250 (0.35 l/ha). Due to a very dry season the level of *Septoria* never developed significantly on the flag leaves. Therefore, the efficacy of the efficacy was mainly assessed as attack on the 2nd and 3rd leaf. The control of *Septoria* on the 2nd leaf varied between 30 and 75% control. Propulse SE 250 + Folicur Xpert, Elatus Era and GF-3307 provided the best control, and 0.4 l/ha Proline EC 250 gave least control (Figure 13). The benefit from adding SDHI was clear when it was compared to using azoles alone even though Bell performed worse than we have seen in other seasons. 1.0 l Propulse SE 250 performed similarly to 1.25 l Viverda. 0.5 l Amistar Gold, 0.75 Viverda and 0.5 Propulse SE 250 + 1.0 Folpan 500 SC all performed slightly worse, and MCW 406s (difenoconazole) as a solo azole performed better than Proline EC 250.

Yield levels were high following irrigation of two trials, but increases from fungicides treatments were genereally low and only 2 of the 3 trials were harvested due to drought. Net yields were not positive and did not reflect the control levels assessed.

Table 10. Effect of ear applications for control of *Septoria* and yield response in wheat. 2 trials (18325).

Treatments, l/ha		% *Septoria*			Yield and increase hkg/ha	Net yield hkg/ha
GS 31-32	GS 51-55	GS 73 L2	GS 73 L3	GS 75 L2		
1. Prosaro EC 250 0.35	Amistar Gold 0.5	6.35	20.25	13.40	1.10	-1.94
2. Prosaro EC 250 0.35	Proline EC 250 0.4	11.15	25.65	20.65	3.55	0.40
3. Prosaro EC 250 0.35	Bell 0.75	8.65	21.55	16.0	1.80	-2.33
4. Prosaro EC 250 0.35	MCW 406s 0.25	8.95	18.90	14.75	3.45	0.90
5. Prosaro EC 250 0.35	Viverda + Ultimate S 0.75 + 0.75	9.40	22.05	14.65	6.05	1.80
6. Prosaro EC 250 0.35	Viverda + Ultimate S 1.25 + 1.0	8.45	21.80	10.65	4.10	-1.71
7. Prosaro EC 250 0.35	Bell + Prosaro EC 250 0.375 + 0.25	7.80	19.80	9.40	1.55	-2.01
8. Prosaro EC 250 0.35	Propulse + Folicur Xpert 0.5 + 0.25	5.15	15.15	7.80	2.95	-0.70
9. Prosaro EC 250 0.35	Propulse 1.0	6.40	17.15	10.55	4.70	0.21
10. Prosaro EC 250 0.35	GF-3307 1.0	7.75	16.90	8.55	5.50	-
11. Prosaro EC 250 0.35	Elatus Era 0.5	6.20	18.80	8.15	4.80	-
12. Prosaro EC 250 0.35	Propulse + Folpan 500 SC 0.5 + 1.0	5.15	19.30	14.15	-2.20	-6.49
13. Prosaro EC 250 0.35	-	8.75	23.50	26.55	1.10	-0.22
1. Untreated	-	15.45	35.0	29.0	96.35	-
No. of trials		2	2	2	2	-
LSD_{95}					NS	-

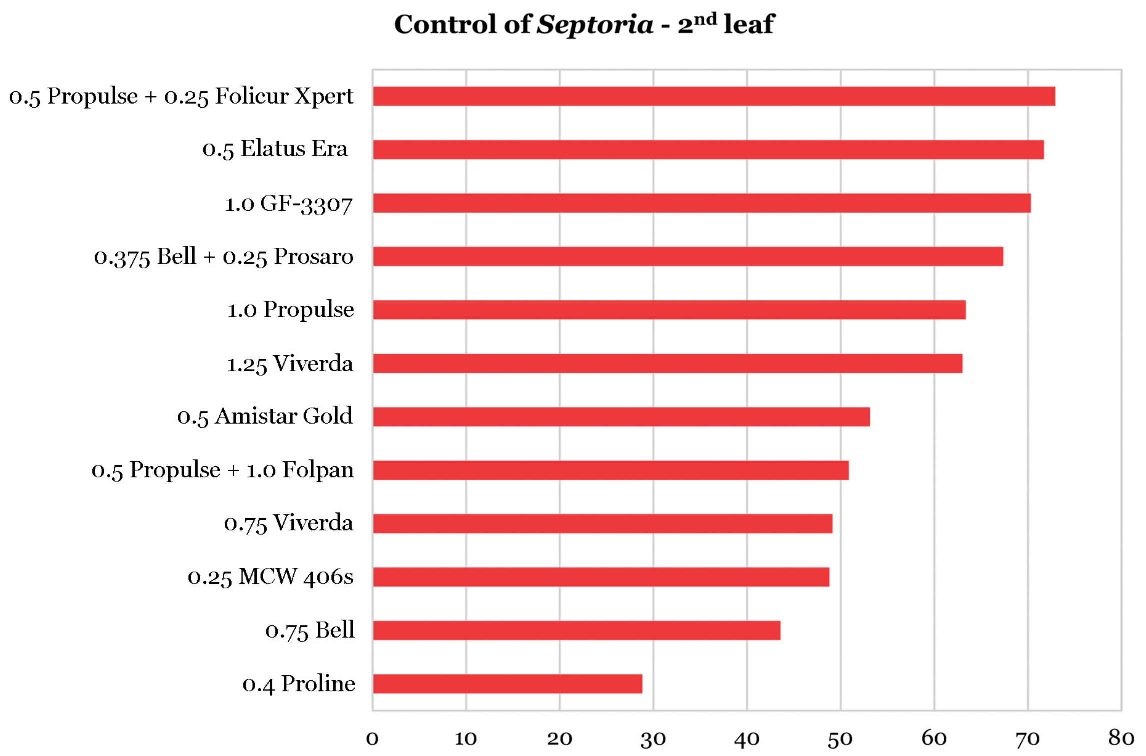


Figure 13. Per cent control of *Septoria* using half rates of several solutions (18325). Average control following a common T1 treatment (0.35 Prosaro EC 250) and one T2 application at GS 45-51.

Control strategies and their impact on selection (18328 & 18345)

In 2018 two other trial plans were tested investigating different control strategies and their impact on control and yield. Leaf samples from these trials will also be investigated for impact on selection for CYP51 mutations. The results from 2018 are shown in Figure 14 and Table 11. Currently only efficacy and yield data are available. The aim of the investigation was to provide most diversity in the choice of actives applied. Due to drought only one of the two trials provided usable data. Most of the solutions provided more than 80% control, and only treatments with 2 x Proline EC 250 provided less control and were used as lower baseline. The more diverse the fungicide programme, the better the level of *Septoria* control and yield response. Treatments with 3 sprays only added a little more to the control and yield compared with two spray strategies and did not improve the net yield.

The new fungicides GF-3307 and Elatus Era were included in the trial plan. These products clearly provided a better control than the old solutions and also slightly better yields than all other treatments (Figure 14; Table 11). Yield responses were low and most treatments gave very similar responses.

Table 11. Effect of ear applications for control of *Septoria* in wheat. 1 trial (18328).

Treatments, l/ha			% *Septoria*			Yield and increase hkg/ha	Net yield hkg/ha
GS 31-32	GS 37	GS 55	GS 69 L3	GS 75 L2	GS 75 L1		
1. Untreated		-	54.9	47.5	10.1	95.40	-
2.	Proline EC 250 0.4	Proline EC 250 0.4	41.3	21.0	1.9	3.1	-0.55
3.	Viverda + Ultimate S 0.75 + 0.75	Proline Xpert 0.5	26.0	14.8	1.1	7.6	2.87
4.	Propulse SE 250 0.75	Proline Xpert 0.5	18.3	11.3	0.4	7.0	2.70
5.	GF-3307 1.0	Proline Xpert 0.5	8.6	7.2	0.2	8.1	-
6.	Viverda + Ultimate S 0.75 + 0.75	MCW 406s 0.25	36.8	18.8	1.2	5.1	0.94
7.	Viverda + Ultimate S 0.75 + 0.75	Propulse SE 250 0.5	27.9	12.4	0.5	3.1	-1.66
8.	Bell + Prosaro 0.375 + 0.25	Proline Xpert 0.5	29.0	19.2	1.1	0.7	-3.34
9.	Elatus Era 0.5	Proline Xpert 0.5	23.3	10.7	0.9	9.5	-
10.	Bell + Orius 200 EW 0.375 + 0.31	Proline Xpert 0.5	20.9	15.1	1.8	0.9	-2.92
11. Prosaro 0.5	Propulse SE 250 + Folicur Xpert 0.5 + 0.25	Proline Xpert 0.5	9.0	8.7	0.4	7.7	1.91
12. Prosaro 0.5	Propulse 0.5	Proline Xpert 0.5	14.1	8.9	0.5	5.5	0.20
13. GF-3307 1.0	GF-3307 1.0	Armure 0.4	3.2	2.1	0.0	7.9	-
No. of trials			1	1	1	1	1
LSD_{95}						7.5	-

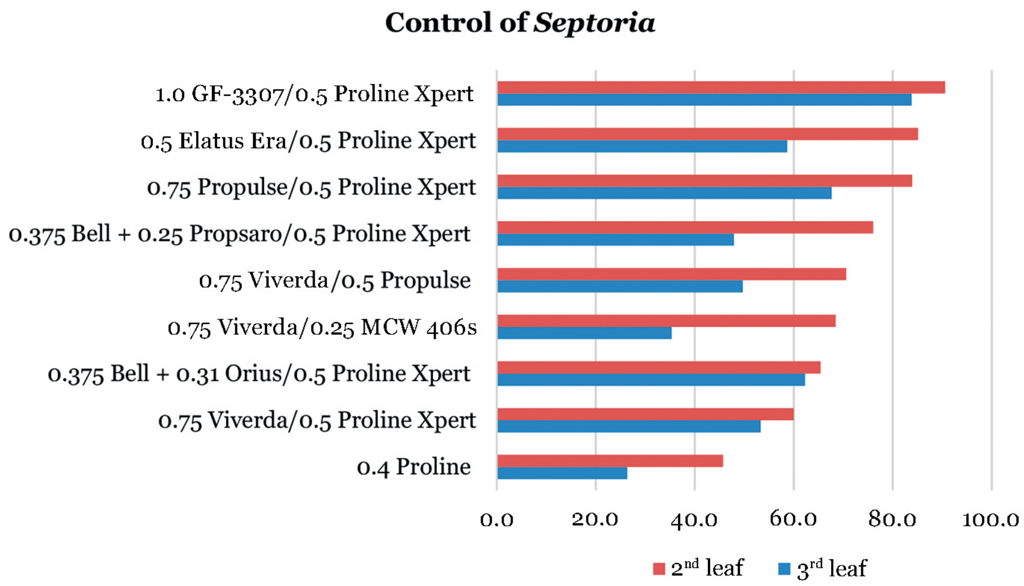


Figure 14. Per cent control of *Septoria* on the flag leaf from different strategies using different timings. Average of 1 trial from 2018 (18328). 35% attack on the 2nd leaf and 55% attack on the 3rd leaf in untreated.

Euro-Res (18345)
A common EU project - Euro-Res - with partners from Sweden, Belgium, Germany, Ireland and Denmark carries out investigations into fungicide resistance in the populations of *Zymoseptoria tritici*. The project aims at testing the sensitivity of populations to different fungicides using both leaf samples and air samples. The project also screens different strategies with the aim to investigate how different treatments and timings select for resistant mutations. The data from the Danish trials in 2018 are shown in Table 12. In this year's trials the early timing provided the best control and the better yield responses, although yield differences were not significant. Combinations of GF-3307 + Elatus Era or Elatus Era + Ascra Xpro provided the best control and yields.

Table 12. Control of *Septoria* and yield responses in 1 trial (18345) in Cleveland using different timings. Euro-Res project.

Treatments, l/ha			% *Septoria*		Yield and increase hkg/ha	Net increase hkg/ha
GS 32	GS 33-37	GS 55	GS 75 L2	GS 77 L2		
1.Untreated			18.8	37.5	91.8	
2.	Proline EC 250 0.8		10.6	20.0	10.2	7.0
3.	Elatus Era 1.0		1.3	1.4	8.0	-
4.	Elatus Era + Bravo 1.0 + 1.0		0.4	0.9	12.8	-
5.		Proline EC 250 0.8	10.0	30.0	2.6	-0.6
6.		Elatus Era 1.0	6.3	8.1	5.2	-
7.		Elatus Era + Bravo 1.0 + 1.0	8.1	4.9	8.7	-
8.	Elatus Era 0.5	Armure 0.4	0.9	2.1	7.2	-
9.	GF-3307 1.0	Elatus Era 0.5	6.5	11.9	18.5	-
10. Proline EC 250 0.4	Elatus Era 0.5	Armure 0.4	0.4	1.3	10.9	-
11.	Elatus Era 0.5	Ascra Xpro 0.5	0.8	1.3	11.5	-
No. of trials			1	1	1	1
LSD_{95}			6.5	7.5	NS	-

EuroWheat project

The EuroWheat project, which was initiated in 2015, included a total of 40 field trials in wheat, following one protocol with 4 azoles used alone or in mixture. Results were published in 2017 (Jørgensen et al., 2018).

The project continued in 2017 and 2018 with a new protocol, which also included azoles tested in 10 countries. The project aims at testing the current European situation regarding control efficacies of different single triazole products against wheat diseases with focus on *Septoria*.

In 2018 15 trials were carried out testing Revysol alone and in mixtures - in comparison with other azoles. The Danish results from 2018 are shown in Figure 15. The season was generally dry in most regions, and the level of *Septoria* was low compared with other seasons. Due to the warm season the attack of brown rust was more pronounced than in other sesaons. Again the efficacy from most azoles was high with the exception of Score (difenoconazole).

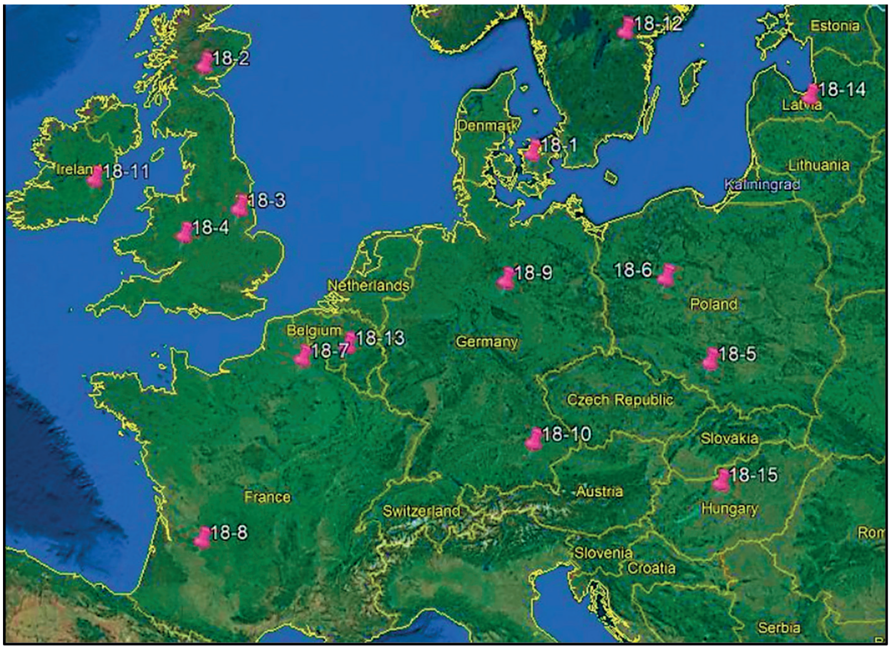


Figure 15. Locations of 15 trials carried out in 2018.

The Danish trial was carried out in the cultivar Hereford, and a clear difference was seen between the tested products. All solutions which included Revysol outperformed the other tested azoles (Table 13). No clear differences were seen between the old azoles. The Danish trial also developed a significant attack of brown rust, and for control of this disease Revysol, Opus and Folicur EW 250 all performed similarly well. Significant increases in yields were harvested in this trial, and again the yield increases from Revysol solutions were better than for the other azoles.

Data from all the trials across Europe with significant attacks of *Septoria* are shown in Figure 16. Per cent control is shown for *Septoria* on the 2nd leaf and brown rust on the flag leaf. Regarding control of *Septoria* a clear advantage to Revysol compounds were seen compared with the other test products. For control of brown rust Revysol, Opus and Folicur EW 250 all showed good control (Figure 17).

Yields increased moderately in the European trials and not all trials provided reliable yield data.
The better treatments increased yields by 12-13 dt/ha. Again Revysol outperformed the other treatments (Figure 18).

Table 13. Per cent control of *Septoria* and brown rust using different azoles in the EuroWheat project. Yield and yield increase (18309).

Treatments, l/ha			% *Septoria*			% brown rust		Yield and increase hkg/ha
GS 37-39			GS 69 L4	GS 73 L3	GS 75 L2	GS 77 L1-2	GS 80 L1	
1.	Untreated		68.8	23.0	12.5	10.0	17.5	93.9
2.	Revysol	1.5	27.5	1.8	1.4	0.1	1.8	15.3
3.	Revysol	0.75	32.5	5.0	1.4	0.1	3.3	13.7
4.	Proline EC 250	0.8	57.5	14.0	5.8	1.5	7.8	11.3
5.	Proline EC 250	0.4	57.5	14.3	8.0	3.5	10.0	9.9
6.	Caramba 60	1.5	47.5	9.3	5.5	0.4	3.5	7.9
7.	Folicur EW 250	1.0	62.5	11.0	4.8	0.2	2.4	13.2
8.	Opus Max	1.5	40.0	6.8	4.8	0.0	3.0	11.7
9.	Score	0.5	32.5	9.8	4.8	1.1	7.3	7.6
10.	Revysol + Proline EC 250	0.75 0.4	27.5	4.5	2.5	0.4	3.0	14.0
11.	BAS 752	1.5	16.3	1.3	0.2	0.1	1.4	15.6
No. of trials			1	1	1	1	1	1
LSD_{95}			24.5	3.4	3.5	0.6	3.8	6.5

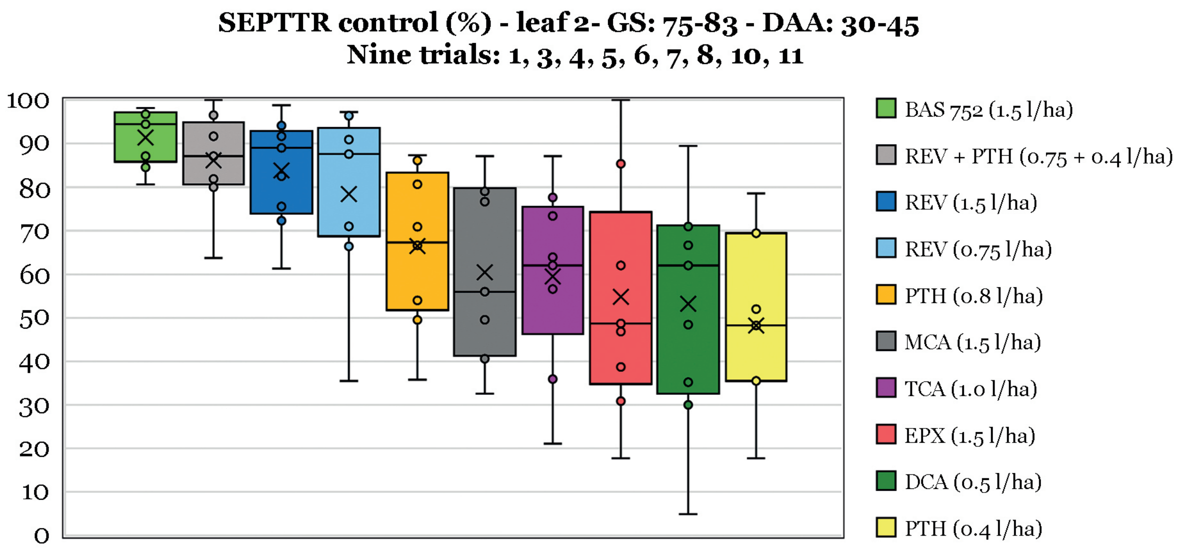


Figure 16. Control of SEPTTR. a) % control of SEPTTR on the 2nd leaf - average of 9 trials. Assessments were carried out at GS 75-85, 30-45 DAA. Treatments are reflecting curative treatments.

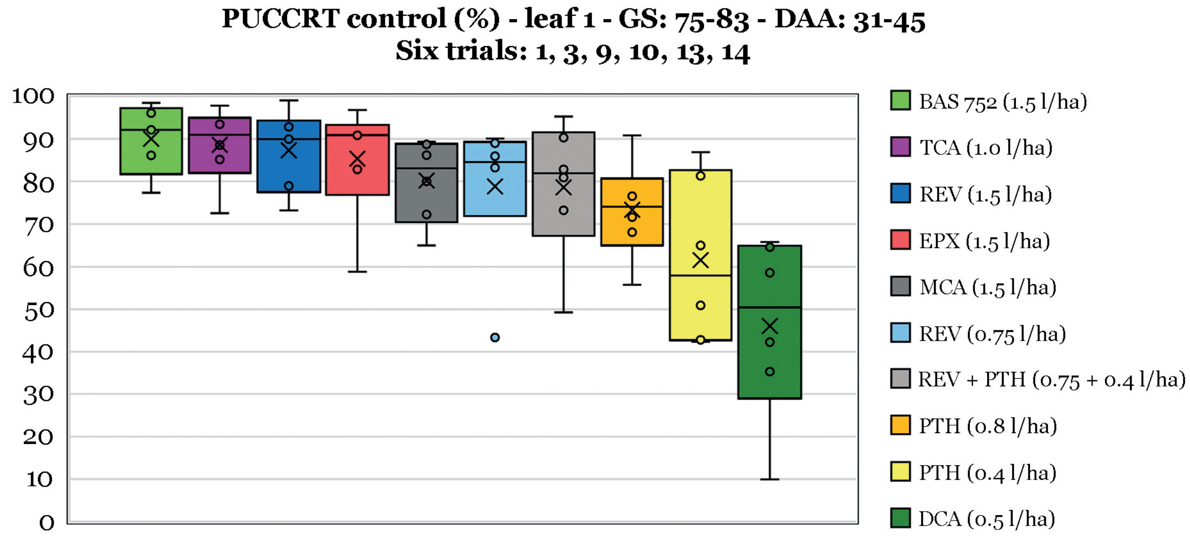


Figure 17. Control of PUCCRE on the flag leaf – average of 6 trials. Treatments are reflecting preventive treatments. Assessments were carried out at GS 75-85, 31-45 DAA.

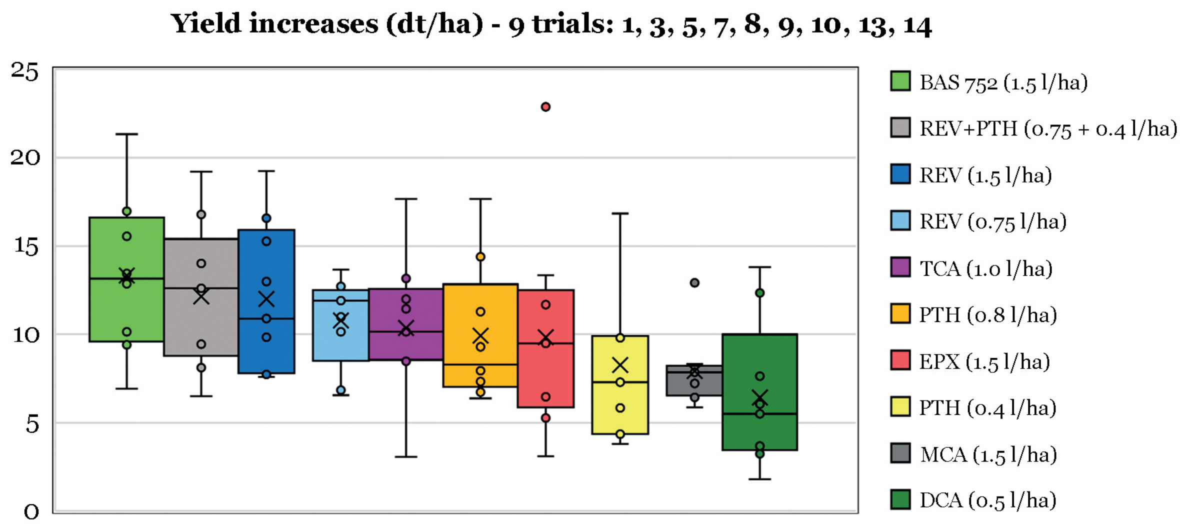


Figure 18. Yield responses in 9 trials in the EuroWheat project from single treatments applied at GS 37-39.

2. Results from fungicide trials in spring barley

Brown rust and minor attacks of net blotch were the most severe diseases in spring barley in 2018. Many combinations of fungicides using azoles and strobilurins provide similar control and yield responses. In most seasons one treatment at GS 37-39 will provide sufficient control using approximately 33-50% rates. In case of early and severe attacks of net blotch, scald and brown rust and late attack of *Ramularia* two treatments might be needed.

In 3 trials in spring barley different fungicide solutions using half rates were compared for control of specific diseases in 2018. Results from the 3 trials are shown in Table 14. One trial was carried out in the mildew susceptible cultivar Milford, which developed a minor to moderate attack of powdery mildew (*Blumeria graminis*). Two trials developed moderate attacks of brown rust (*Puccinia hordei*) and a minor attack of net blotch (*Pyrenophora teres*). One of the 3 trials suffered so much from drought that it was not possible to carry out assessments, and it was decided not to harvest the trial. As shown in Table 14, most of the tested solutions provided very similar and good control of all diseases assessed, with the exception of Propulse SE 250 + Folpan 500 SC for control of rust. Adding Comet Pro to Propulse SE 250 improved the control of rust significantly (Figure 19). Overall, the new test product Elatus Era provided the best disease control. Yield responses were small and did not differ significantly for the different treatments.

Table 15 summarises the efficacy data on brown rust and the yield data from trials carried out in 2016, 2017 and 2018. With the exception of Propulse SE 250 used alone, all treatments provided very similar control and yields.

Table 14. Disease control using different fungicides applied at GS 33-37 in spring barley. 2 trials 2018 (18383).

Treatments, l/ha GS 37	% brown rust		% mildew	% leaf blotch	% GLA	Yield and increase hkg/ha	Net yield hkg/ha
	GS 71-73 L 2-3	GS 75-77 L 2-3	GS 71 L 3	GS 73 L 2-3	GS 75/77		
1. Proline Xpert + Bell 0.25 + 0.375	0.2	0.2	0.5	0.0	91.4	4.6	2.3
2. Prosaro + Comet Pro 0.35 + 0.2	0.2	0.9	0.3	0.0	91.7	1.8	-0.1
3. Bell + Comet Pro 0.375 + 0.31	0.2	0.6	0.5	0.0	92.7	3.0	0.6
4. Viverda + Ultimate S 0.75 + 0.75	0.1	0.2	0.3	0.0	94.3	4.7	1.7
5. Propulse + Folpan 0.5 + 1.0	1.9	5.5	0.9	0.0	81.3	5.5	2.5
6. Propulse + Comet Pro 0.5 + 0.3	0.1	1.5	0.4	0.0	86.7	5.9	3.3
7. Elatus Era 0.5	0.1	0.1	0.2	0.0	94.2	5.8	-
8. Untreated	11.2	20.6	13.0	1.5	62.3	74.2	-
No. of trials	2	2	1	1	2	2	2
LSD_{95}	1.59	2.46	1.9	0.30	8.5	6.56	-

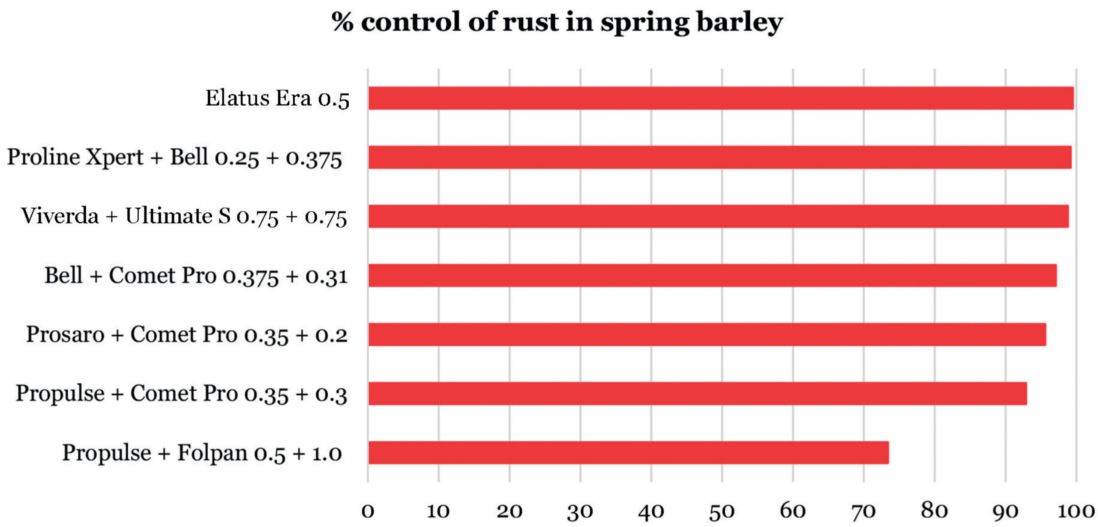


Figure 19. Control of rust in spring barley (18383). Average of 2 trials with 20.7% attack of brown rust in untreated.

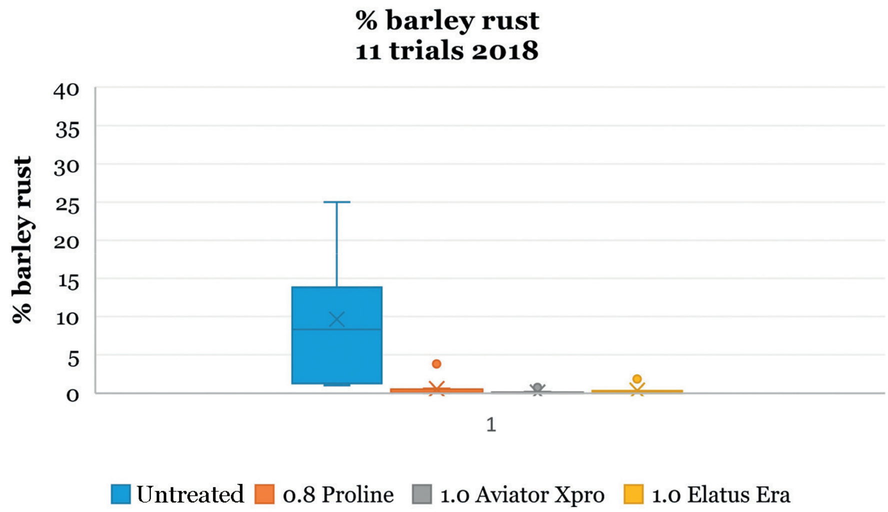
Table 15. Disease control using different fungicides applied at GS 33-37 in spring barley. Average of 8 trials from 2016 (16343), 2017 (17361) and 2018 (18383). *Dose varied across years.

Treatments GS 37-39	l/ha	% brown rust 2017+2018 GS 75	2016-17 yield increase hkg/ha	2017-18 yield increase hkg/ha	Net yield hkg/ha
1. Proline Xpert + Bell	0.25 + 0.375	8.0	9.4	8.5	6.1
2. Prosaro 250 EC + Comet Pro	0.375 + 0.25	10.5	9.3	6.7	4.7
3. Bell + Comet Pro	0.375 + 0.31	9.4	11.7	8.5	6.0
4. Viverda + Ultimate	0.75 + 0.75	6.4	12.0	10.0	7.0
5. Propulse + Comet Pro	0.5 + 0.3*	13.6	7.4	8.9	1.2
6. Elatus Era	0.5	7.6		12.0	-
7. Untreated		33.9	61.1	60.9	-
No. of trials		5	6	5	5
LSD_{95} (excl. untreated)			4.9	3.5	-

In several trials Proline EC 250 and Aviator Xpro or Elatus Era were used as reference products for testing different development products. The data are summarised in Table 16, in which it should be noted that the number of trials with Elatus Era is lower than for the two other products. The level of efficacy is also visualised in the box plot figures shown in Figure 20. As expected, all 3 products provided high levels of rust control, while a clearer difference was seen for control of net blotch, in which Aviator Xpro and Elatus Era outperformed Proline EC 250.

Table 16. Disease control using different fungicides applied at GS 37-39 in trials with both spring barley and winter barley. *Elatus Era was only present in 7 rust trials, 5 net blotch trials and 6 yield trials.

Treatment, l/ha GS 39	% barley rust GS 75	% net blotch GS 73	Yield and increase hkg/ha	Net yield hkg/ha
1. Proline EC 250 0.8	0.5	3.3	5.6	2.4
2. Aviator Xpro 1.0	0.1	2.4	6.3	-
3. Elatus Era 1.0	0.4*	2.6*	3.9*	-
4. Untreated	9.6	14.0	69.3	-
No. of trials	11	8	10	
			NS	



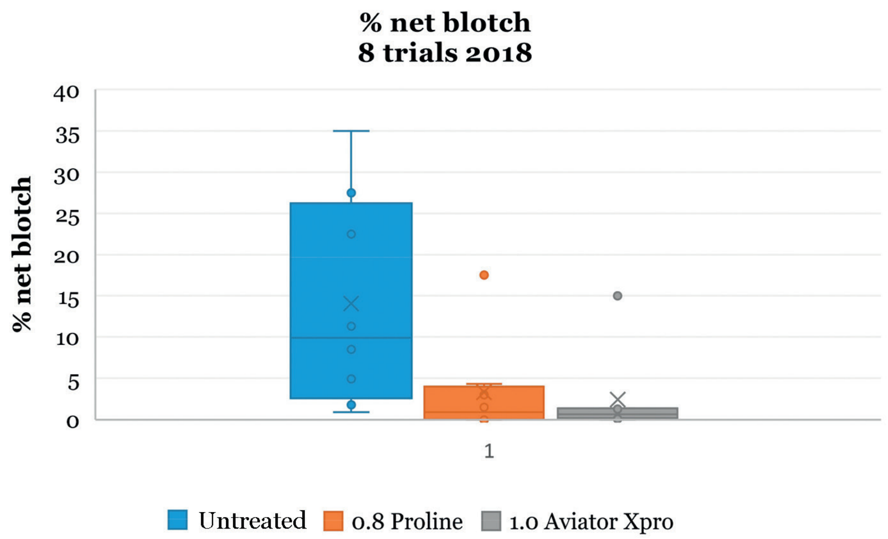
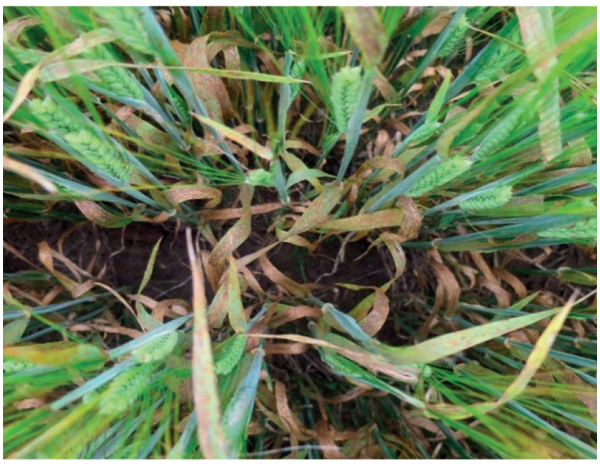


Figure 20. Summary of reference treatments from development trials in both winter barley and spring barley.



Untreated plot in the cultivar Soulmate with a lot of brown rust.

Plot treated with 0.5 Elatus Era applied at GS 37 and providing good control of both brown rust and Ramularia leaf spot.

3. Results from fungicide trials in winter barley

Brown rust, net blotch, scald, powdery mildew and *Ramularia* are the most severe diseases in winter barley. Many combinations of fungicides using azoles and strobilurins provide similar control and yield responses. In most seasons one treatment at GS 37-39 will provide sufficient control using approximately 33-50% rates. In case of early and severe attack of net blotch, scald and brown rust and late attack of *Ramularia* two treatments might be needed.

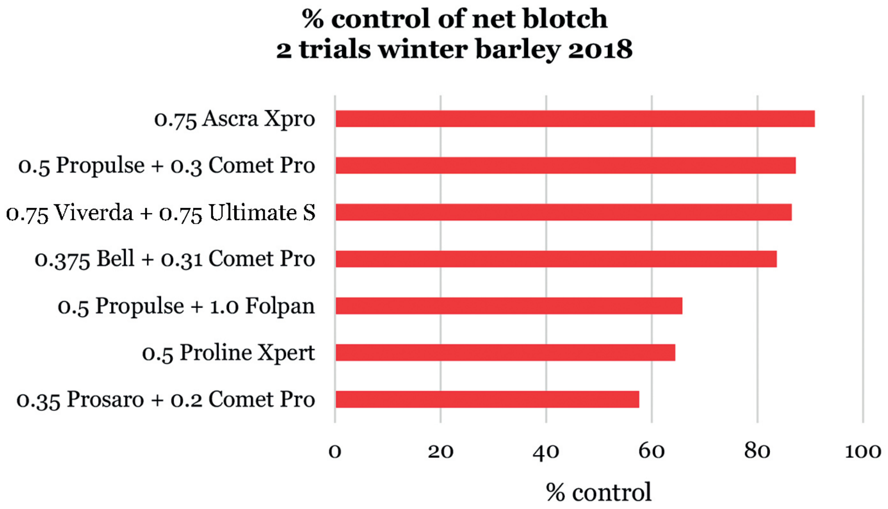
In 2018 3 trials in winter barley were carried out testing different combinations of fungicide solutions against specific diseases. Treatments were applied at GS 37-39 using half rates, which have typically been seen as economically optimal solutions. Results from the trials are shown in Table 17. The trials in 2017 were dominated by brown rust (*Puccinia hordei*) and net blotch (*Pyrenophora te*res). As shown in Table 17 and Figure 21 most of the tested solutions provided very similar and good control of all diseases assessed. With the exception of Propulse SE 250 + Folpan 500 SC all treatments gave good control of brown rust. The attack of net blotch was slight to moderate and solutions which did not contain both SDHIs and strobilurins did not perform so well. Yield increases varied between 2.6 and 10 hkg/ha. Due to the dominance of brown rust Propulse SE 250 + Folpan 500 SC was inferior on yields.

In Table 18 data from several seasons are summarised. This table confirms that several solutions give very similar yield increases and also similar net yields.

Table 19 summarises data from two trials carried out in 2018 to investigate which fungicides will provide best control of *Ramularia*. Due to the dry season only a minor attack of *Ramularia* developed, which did not make it possible to rank the efficacy of the products. The trial was first treated with Comet Pro to eliminate problems with rust and net blotch diseases. Even so, the 2^{nd} spray did still show variable control of also rust and leaf blotch diseases. Overall, Ascra Xpro provided the best control of both net blotch and rust diseases followed by Propulse SE 250. Products like Kumulus S, Folpan 500 SC and Dithane NT showed a control inferior to other systemic fungicides.

Table 17. % control of net blotch and brown rust in winter barley using different azoles. Green leaf area, yield and yield increase (18389).

Treatments, l/ha	% net blotch		% brown rust		% GLA	Yield and increase hkg/ha	Net yield hkg/ha
GS 39	GS 65-69 L 2-3	GS 73 L 1-2	GS 65 L 2-3	GS L 2-3	GS L 2-3		
1. Proline Xpert 0.5	4.88	12.0	0.43	5.52	9.4	5.35	3.6
2. Bell + Comet Pro 0.375 + 0.31	2.38	5.30	0.15	1.65	21.9	9.25	6.8
3. Viverda + Ultimate S 0.75 + 0.75	1.46	5.30	0.03	1.54	33.75	10.10	7.2
4. Prosaro + Comet Pro 0.35 + 0.2	4.0	15.80	0.18	2.37	23.15	10.0	8.2
5. Propulse + Folpan 0.5 + 1.0	5.03	9.0	3.5	9.67	10.05	2.60	-0.4
6. Propulse + Comet Pro 0.5 + 0.3	1.19	5.30	0.08	2.26	31.25	10.20	7.6
7. Ascra Xpro 0.75	1.70	2.30	0.13	2.04	30.0	9.60	-
8. Untreated	20.13	23.80	16.25	20.43	3.15	63.15	-
No. of trials	2	1	1	3	2	2	2
LSD_{95}	2.71	6.35	1.65	2.48	20.97	5.94	-



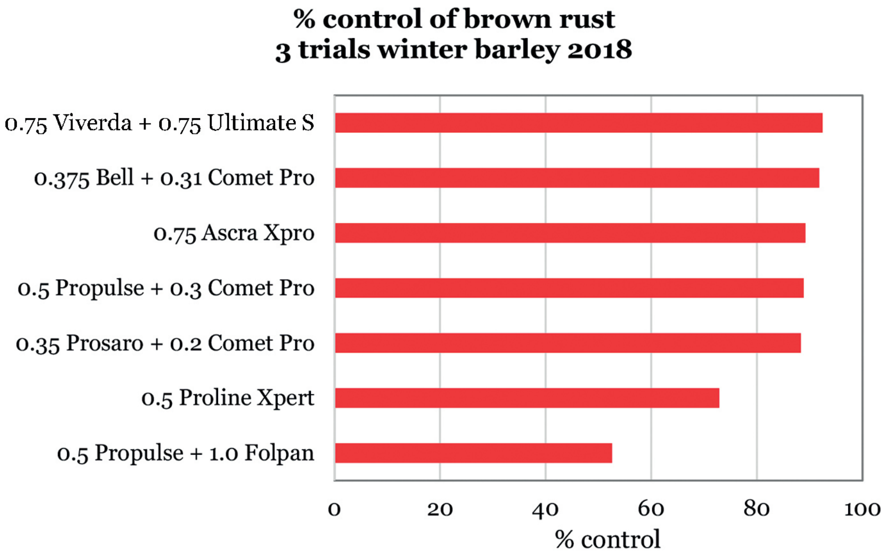


Figure 21. Average of 2 trials with 26.3% attack of net blotch in untreated and 20.4% attack of brown rust in 3 trials.

Table 18. Yield increases from disease control in winter barley using treatments at GS 37-39. Averages from different years.

Treatments GS 37-39	l/ha	Yield increase hkg/ha						Net yield hkg/ha 2016-18
		2010-2016	2013-2016	2015-2017	2016+2017	2018	2016-18	
1. Proline Xpert	0.5				+9.4	+5.4	+8.1	6.3
2. Bell + Comet Pro	0.375 + 0.25	+7.8	+8.0	+10.3	+10.6	+9.0	+10.1	7.8
3. Viverda	0.75	-	+8.3	+11.0	+12.0	+8.4	+10.8	7.9
4. Prosaro EC 250	0.5	+.6.5	+6.8	-	-	-	-	-
5. Prosaro EC 250 + Comet Pro	0.25 + 0.31	-	-	+10.4	+10.3	+8.4	+9.7	7.9
6. Propulse SE 250	0.5	-	-	-	+7.9	-	-	-
7. Propulse SE 250 + Comet Pro	0.25 + 0.31	-	-	-	+11.6	+8.8	+10.7	8.8
8. Proline EC 250 + Bell	0.2 + 0.375	-	-	+9.2	+10.3	-	-	-
9. Untreated		70.1	66.2	59.3	61.2	65.0	62.5	-
No. of trials			19	9	6	3	9	9
LSD_{95}		3.0	1.9	2.5	3.2	-		

Table 19. Per cent control of net blotch, brown rust and *Ramularia* in winter and spring barley using different azoles. Yield and yield increase (18385-1 + 18385-2).

Treatments, l/ha	% brown rust	% net blotch	% Ramularia	Yield and	Net yield hkg/ha
GS 32-33 / GS 45-51	GS 75-77 L 1-3 WB+SB	GS 75 L 1-2 WB	GS 75 L 1-2 WB	increase hkg/ha WW+SB	
1. Comet Pro 0.5 / Untreated	7.90	32.50	2.25	69.15	-
2. Comet Pro 0.5 / Ascra Xpro 0.75	1.30	0.10	0.03	+5.80	-
3. Comet Pro 0.5 / Propulse 0.8	2.34	0.40	0.08	+6.55	2.2
4. Comet Pro 0.5 / Proline EC 250 0.4	4.15	20.0	0.35	+4.25	0.7
5. Comet Pro 0.5 / Bravo 1.0	7.13	17.50	0.60	+3.25	-
6. Comet Pro 0.5 / GF-3307 0.75	2.82	10.0	0.25	+5.20	-
7. Comet Pro 0.5 / Dithane NT 1.5	7.15	30.0	0.25	+2.25	-1.61
8. Comet Pro 0.5 / Kumulus 4.0	9.88	27.50	0.63	0.10	-6.85
9. Comet Pro 0.5 / Folpan 1.0	6.65	27.50	0.35	+2.30	-1.04
10. Comet Pro 0.5 / Revysol 0.75	4.25	17.50	0.18	+6.05	-
No. of trials	2	1	1	2	2
LSD_{95}		5.8	1.1	NS	-

4. Cultivar susceptibility to Fusarium head blight

The Department of Agroecology, Aarhus University, Flakkebjerg has in line with previous years in a project partly financed by the breeders investigated the susceptibility to Fusarium head blight (FHB) and tan spot of the cultivars most commonly grown in Denmark. In this year's trials 22 cultivars were included. The trial was inoculated during flowering.

Trial with inoculation during flowering. Two rows of 1 metre were sown in the autumn per cultivar and four replicates were included. The trial was inoculated 3 times between 1, 3 and 6 June, using a spore solution consisting of both *Fusarium culmorum* and *Fusarium graminearum*. To stimulate the development of the disease, the trial was irrigated by a mist irrigation system 2 times per day. Wheat is most susceptible during flowering, and at the time of inoculation the degree of flowering was assessed to ensure that all cultivars were inoculated during flowering. Approximately 15 days after inoculation the first symptoms of Fusarium head blight were seen.

The trial was assessed counting the attack on 100 ears per cultivar per replicate. Also the degree of attack was scored as an average of the ears attacked using a 1-9 scale. Based on these results a *Fusarium* index was calculated. Results are shown in Figure 22 and Table 20.

The small plots were hand harvested, and grains were investigated for content of the mycotoxins deoxynivalenol (DON), nivalenol (NIV), zearalenone (ZEA), HT-2 and T-2. The contents of HT-2 and T-2 were very low in the trials and therefore not included. All cultivars had DON levels much higher than the maximum acceptable limit of 1250 ppb. There was quite a good correlation between the degree of attack and the content of DON and between the contents of DON and NIV. The content of ZEA was also quite high, and this content also linked quite well to the attack of Fusarium head blight (Figure 23).

As seen in Figure 22, Torp, RGT Universe, SJ L 288 and Kalmar had the most severe attacks, and least attack was seen in Safari, Creator, Benchmark, Sheriff and Elixer. The cultivars Ritmo and Oakley were used as susceptible reference cultivars and Olivin and Skalmeje as the most resistant references.

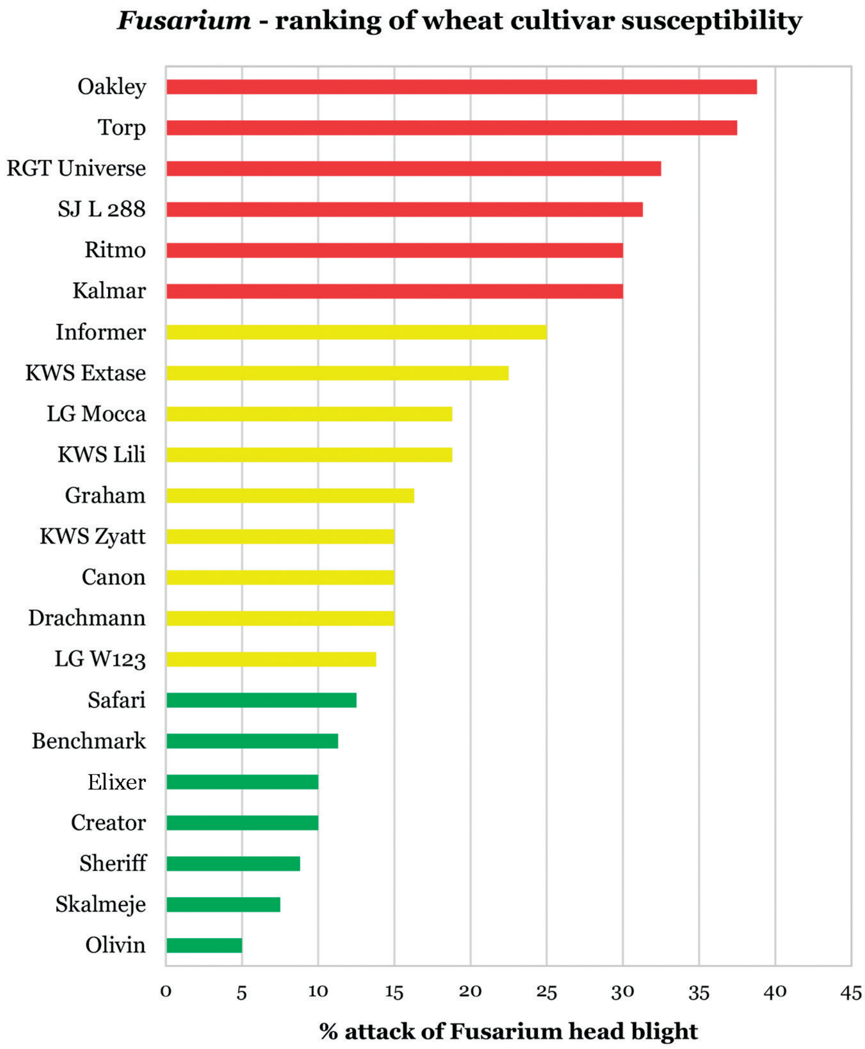


Figure 22. Per cent attack of Fusarium head blight in late July. Average of both trials. The LSD_{95} value = 6.9.

In Table 20 the ranking of cultivars to *Fusarium* susceptibily is summarised, including also data from previous years in the final ranking. The results from the trials were published in July together with SEGES in order to make the data available for the cultivar choice in 2018.

Table 20. Grouping of cultivars by susceptibility to Fusarium head blight. Based on results from both 2018 and previous years.

Low susceptibility	Moderate to high susceptibility	High susceptibility
Benchmark, Creator, Elixer, Sheriff	Informer, KWS Extase, LG Mocca, KWS Lili, Graham, KWS Zyatt, Canon, Drachmann, LG W123	Kalmar, Torp, Oakley, Ritmo, Torp, Pistoria

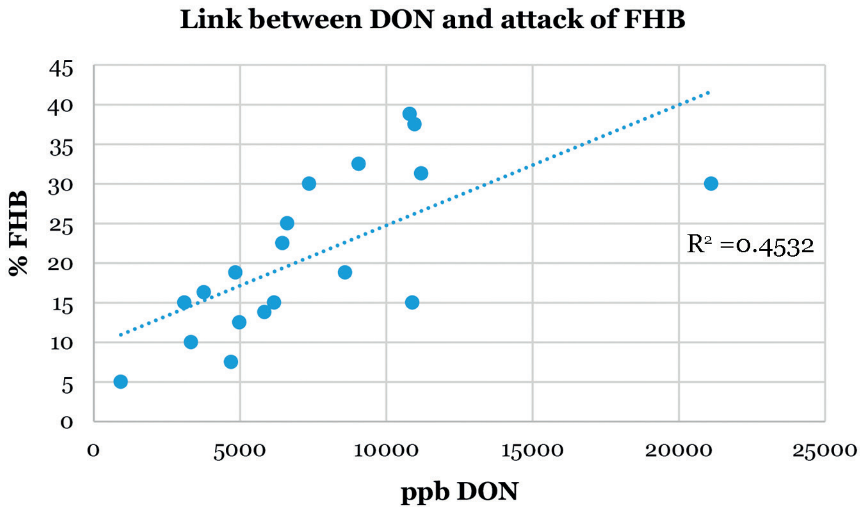


Figure 23. Correlation between % heads attacked by *Fusarium* and content of DON measured in harvested grain. Data from one trial inoculated with spores in 2018.

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III Control strategies in different cultivars

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Data from 6 wheat cultivars

Eight different control strategies were compared in 6 different wheat cultivars. One of the treatments included the use of the decision support system Crop Protection Online (CPO) to evaluate the need for treatments. The trials were placed at two sites - one at AU Flakkebjerg and one near Horsens (Jutland) with LMO.

The following strategies were tested:

1. Untreated
2. 1.25 l/ha Viverda + 1.0 l/ha Ultimate S (GS 45-51)
   0.6 l/ha Viverda + 0.6 l/ha Ultimate S / 0.3 l/ha Bell + 0.15 l/ha Proline EC 250 (GS 37-39 & 55-61)
   0.35 l/ha Prosaro EC 250 / 0.6 l/ha Viverda + 0.6 l/ha Ultimate S / 0.3 l/ha Bell + 0.15 l/ha Proline EC 250 (GS 32/37-39 & 55-61)
5. 0.35 l/ha Prosaro EC 250 / 1.25 l/ha Viverda + 1.0 l/ha Ultimate S / 0.6 l/ha Bell + 0.3 l/ha Proline EC 250 (GS 32/37-39 & 55-61)
6. CPO (Table 1)

Table 1. Treatments applied following recommendations from CPO (18350-1 and 18350-2).

Cultivars (18350-1)	Date	Products, l/ha	TFI	Costs, hkg/ha
Susceptible mixture (Mixture S)	29-05-2018	Bell + Comet Pro 0.64 + 0.12	0.87	2.8
Resistant mixture (Mixture R)	-	-	-	-
Benchmark	29-05-2018	Bell + Comet Pro 0.64 + 0.12	0.87	2.8
Torp	29-05-2018	Bell + Comet Pro 0.64 + 0.12	0.87	2.8
Hereford	29-05-2018	Bell + Comet Pro 0.64 + 0.12	0.87	2.8
Sheriff	-	-		-
Informer	-	-		-
Creator	06-06-2018	Bell + Comet Pro 0.35 + 0.12	0.52	1.9

Due to drought, it was not possible to do any proper disease assessments in the trial at LMO. Also, in this trial no treatments were carried out using CPO.

The trial at Flakkebjerg was irrigated twice with 30 mm, which saved the trial from severe drought. The 3 susceptible cultivars and the susceptible mixture were treated against *Septoria* on 29 May due to *Septoria* attack on the 3rd leaf. Benchmark also had an attack of yellow rust and later this was also seen in Creator, which was treated on 6 June. Late in the season, all cultivars developed a minor to moderate attack of brown rust.

The trial showed clear differences in the level of *Septoria* attack between cultivars, mainly from the assessment on the 3rd leaf. The 3 resistant cultivars all had a very low level of attack compared with the susceptible cultivars. Assessed on the 3rd leaf, the different treatments only resulted in a small reduction of the attack (Table 2).

The attack of brown rust was most pronounced in Hereford but was well controlled from all treatments.

As found in other trials as well, the trials confirmed that in 2018 yields were not significantly improved from any treatments. The treatments applied to CPO did not positively improve yields. Even though the crop was kept alive longer due to irrigation, the crop was still forced to senescence earlier than normal because of drought.

The results shown in Figure 1 indicate that the *Septoria* attack was very different in the two groups but that yields were still very similar.

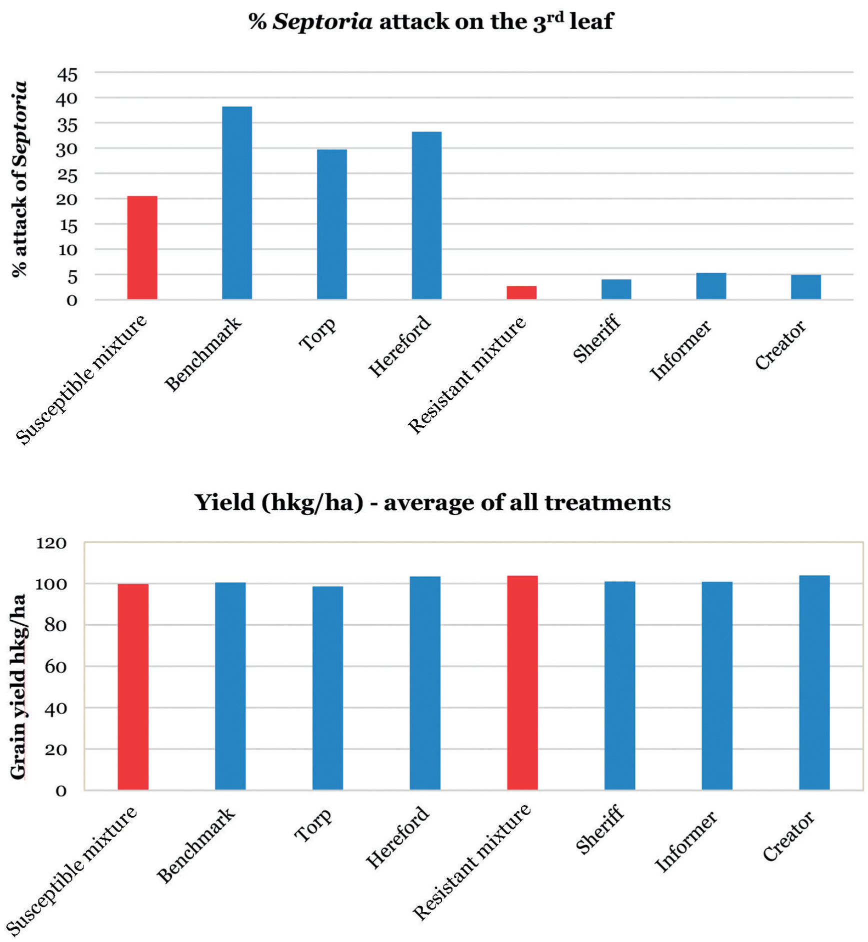

Figure 1. Data from cultivar trial at Flakkebjerg (18350-1), which showed variation in susceptibility to *Septoria* and very similar yield levels at approximately 10 t/ha.

Table 2. % control of diseases, green leaf area and yield responses. 1 trial from Flakkebjerg with 6 winter wheat cultivars, using 5 different fungicide treatments (18350). (Continues on the next page).

Cultivars (18350-1)	% *Septoria*, leaf 3, GS 73						% brown rust, leaf 2, GS 75					
	Untr.	1.25 Viverda + 1.0 Ultimate S	0.6 Viverda + 0.6 Ultimate S / 0.3 Bell + 0.15 Proline	0.35 Prosaro / 0.6 Viverda + 0.6 Ultimate S / 0.3 Bell + 0.15 Proline	0.35 Prosaro / 1.25 Viverda + 1.0 Ultimate S / 0.6 Bell + 0.3 Proline	CPO	Untr.	1.25 Viverda + 1.0 Ultimate S	0.6 Viverda + 0.6 Ultimate S / 0.3 Bell + 0.15 Proline	0.35 Prosaro / 0.6 Viverda + 0.6 Ultimate S / 0.3 Bell + 0.15 Proline	0.35 Prosaro / 1.25 Viverda + 1.0 Ultimate S / 0.6 Bell + 0.3 Proline	CPO
Mixture S	11.3	9.7	10.0	7.3	8.0	10.0	3.3	0	0	0	0	0.2
Mixture R	3.0	2.3	1.0	2.3	1.0	1.3	0.6	0	0	0	0	0.4
Benchmark	28.3	23.3	18.3	15.7	13.3	20.0	3.7	0	0	0	0	0.0
Torp	16.7	11.7	13.3	8.0	7.3	10.0	5.3	0	0	0	0	0.0
Hereford	15.0	23.3	15.0	14.0	10.0	23.3	10.0	0	0	0	0	0.1
Sheriff	2.7	2.7	1.7	1.7	1.0	1.7	0.1	0	0	0	0	0.1
Informer	2.7	3.0	1.7	3.0	2.0	2.0	0.6	0	0	0	0	0.6
Creator	2.0	2.7	1.0	1.0	0.3	1.0	1.0	0	0	0	0	0.1
Average	10.2	9.8	7.8	6.6	5.4	8.7	3.1	0	0	0	0	0.2
No. of trials	1						1					

Cultivars (18350-1)	% green area, leaf 1, GS 77						TGW (g)					
	Untr.	1.25 Viverda + 1.0 Ultimate S	0.6 Viverda + 0.6 Ultimate S / 0.3 Bell + 0.15 Proline	0.35 Prosaro / 0.6 Viverda + 0.6 Ultimate S / 0.3 Bell + 0.15 Proline	0.35 Prosaro / 1.25 Viverda + 1.0 Ultimate S / 0.6 Bell + 0.3 Proline	CPO	Untr.	1.25 Viverda + 1.0 Ultimate S	0.6 Viverda + 0.6 Ultimate S / 0.3 Bell + 0.15 Proline	0.35 Prosaro / 0.6 Viverda + 0.6 Ultimate S / 0.3 Bell + 0.15 Proline	0.35 Prosaro / 1.25 Viverda + 1.0 Ultimate S / 0.6 Bell + 0.3 Proline	CPO
Mixture S	80.0	83.3	83.3	83.3	83.3	86.7	42.0	42.4	41.7	42.4	42.7	45.2
Mixture R	93.3	88.3	88.3	86.7	90.0	90.0	44.1	44.5	44.3	44.4	45.1	43.9
Benchmark	63.3	76.7	73.3	84.3	73.3	83.3	41.7	40.9	41.9	42.5	42.8	42.8
Torp	80.0	80.0	88.0	86.7	86.7	76.7	41.2	42.4	41.2	42.7	41.6	42.3
Hereford	46.7	86.7	83.3	83.3	90.0	80.0	44.1	46.8	45.7	46.0	44.0	44.8
Sheriff	80.0	86.7	83.3	76.7	80.0	90.0	41.3	40.1	42.0	43.1	41.5	44.1
Informer	95.0	90.0	93.3	91.7	80.0	95.0	47.9	46.4	48.9	44.9	43.6	46.3
Creator	73.3	90.0	90.0	86.7	90.5	90.0	42.7	41.1	44.1	44.3	44.5	43.5
Average	76.5	85.2	85.4	84.9	84.2	86.5	43.1	43.1	43.7	43.8	43.2	44.1
No. of trials	1						1					

Table 2. % control of diseases, green leaf area and yield responses. 1 trial from Flakkebjerg with 6 winter wheat cultivars, using 5 different fungicide treatments (18350). (Continued).

Cultivars (18350-1)	Yield and increase, hkg/ha						Net increase, hkg/ha				
	Untr.	1.25 Viverda + 1.0 Ultimate S	0.6 Viverda + 0.6 Ultimate S / 0.3 Bell + 0.15 Proline	0.35 Prosaro / 0.6 Viverda + 0.6 Ultimate S / 0.3 Bell + 0.15 Proline	0.35 Prosaro / 1.25 Viverda + 1.0 Ultimate S / 0.6 Bell + 0.3 Proline	CPO	1.25 Viverda + 1.0 Ultimate S	0.6 Viverda + 0.6 Ultimate S / 0.3 Bell + 0.15 Proline	0.35 Prosaro / 0.6 Viverda + 0.6 Ultimate S / 0.3 Bell + 0.15 Proline	0.35 Prosaro / 1.25 Viverda + 1.0 Ultimate S / 0.6 Bell + 0.3 Proline	CPO
Mixture S	99.5	3.7	4.1	5.0	-1.9	5.1	-1.2	-0.3	-0.7	-11.1	2.3
Mixture R	103.1	-1.2	-2.1	-8.7	-2.6	-8.3	-6.1	-6.5	-14.4	-11.8	-8.3
Benchmark	98.4	-1.1	-4.0	3.6	-2.0	11.1	-6.0	-8.4	-2.1	-11.2	8.3
Torp	103.0	6.0	-0.6	-1.3	-8.4	-0.3	1.1	-5.0	7.0	-17.6	3.1
Hereford	103.6	-1.4	5.5	0.6	2.9	2.1	-6.3	1.1	-5.1	-6.3	-0.7
Sheriff	97.7	7.2	-2.8	8.0	5.3	8.0	2.3	7.2	2.3	-3.9	8.0
Informer	98.7	7.5	-1.2	-0.7	7.6	7.5	2.6	5.6	-6.4	-1.6	7.5
Creator	103.0	-1.0	1.3	2.0	4.3	-0.3	-5.9	-3.1	3.7	-4.9	-2.2
LSD_{95}		NS									
Average	100.9	2.5	0.1	1.1	0.7	3.1	-2.4	-1.2	-2.0	-8.6	2.3
No. of trials	1	1	1	1	1	1	1	1	1	1	1

Untr. = Untreated; 1.25 l/ha Viverda + 1.0 l/ha Ultimate S, GS 45-51 (costs = 4.9 hkg/ha); 0.6 l/ha Viverda + 0.6 l/ha Ultimate S, GS 37-39 / 0.3 l/ha Bell + 0.15 l/ha Proline EC 250, GS 55-61 (costs = 4.36 hkg/ha); 0.35 Prosaro EC 250, GS 32 / 0.6 l/ha Viverda + 0.6 l/ha Ultimate S, GS 37-39 / 0.3 l/ha Bell + 0.15 l/ha Proline EC 250, GS 55-61 (costs = 5.68 hkg/ha); 0.35 l/ha Prosaro EC 250, GS 32 / 1.25 l/ha Viverda + 1.0 l/ha Ultimate S, GS 37-39 / 0.6 l/ha Bell + 0.3 l/ha Proline EC 250, GS 55-61 (costs = 9.16 hkg/ha); CPO = Crop Protection Online.

Table 2. % control of diseases, green leaf area and yield responses. 1 trial from Flakkebjerg with 6 winter wheat cultivars, using 5 different fungicide treatments (18350). (Continued).

Cultivars (18350-2)	Yield and increase, hkg/ha						Net increase, hkg/ha				
	Untr.	1.25 Viverda + 1.0 Ultimate S	0.6 Viverda + 0.6 Ultimate S / 0.3 Bell + 0.15 Proline	0.35 Prosaro / 0.6 Viverda + 0.6 Ultimate S / 0.3 Bell + 0.15 Proline	0.35 Prosaro / 1.25 Viverda + 1.0 Ultimate S / 0.6 Bell + 0.3 Proline	CPO	1.25 Viverda + 1.0 Ultimate S	0.6 Viverda + 0.6 Ultimate S / 0.3 Bell + 0.15 Proline	0.35 Prosaro / 0.6 Viverda + 0.6 Ultimate S / 0.3 Bell + 0.15 Proline	0.35 Prosaro / 1.25 Viverda + 1.0 Ultimate S / 0.6 Bell + 0.3 Proline	CPO
Mixture M	63.8	-0.6	-4.3	-5.3	-3.2	-4.7	-5.5	-8.7	-11.0	-12.4	-4.7
Mixture R	53.5	1.8	1.3	-3.6	-0.7	-1.2	-3.1	-3.1	-9.3	-9.9	-1.2
Benchmark	57.5	2.7	12.1	-0.1	4.7	4.5	-2.2	7.7	-5.8	-4.7	4.5
Torp	648	4.1	6.7	6.8	8.0	8.8	-0.8	2.3	1.1	-1.2	8.8
Hereford	68.7	0.6	-2.3	-1.3	-1.5	-2.9	4.3	-6.7	8.0	-10.7	-2.9
Sheriff	59.8	-0.6	-1.2	0.6	-0.2	-1.7	5.5	-5.6	-5.1	-9.4	-1.7
Informer	58.2	1.1	0.5	2.9	1.6	-5.0	-3.8	-3.9	-2.8	7.6	-5.0
Creator	51.0	3.6	3.9	5.5	5.2	7.3	-1.3	-0.5	-0.2	-4.0	7.3
LSD_{95}		NS									
Average		1.6	2.1	0.7	1.7	0.6	-0.9	-2.3	-3.1	-5.6	0.6
No. of trials	1	1	1	1	1	1	1	1	1	1	1

Untr. = Untreated; 1.25 l/ha Viverda + 1.0 l/ha Ultimate S, GS 45-51 (costs = 4.9 hkg/ha); 0.6 l/ha Viverda + 0.6 l/ha Ultimate S, GS 37-39 / 0.3 l/ha Bell + 0.15 l/ha Proline EC 250, GS 55-61 (costs = 4.36 hkg/ha); 0.35 Prosaro EC 250, GS 32 / 0.6 l/ha Viverda + 0.6 l/ha Ultimate S, GS 37-39 / 0.3 l/ha Bell + 0.15 l/ha Proline EC 250, GS 55-61 (costs = 5.68 hkg/ha); 0.35 l/ha Prosaro EC 250, GS 32 / 1.25 l/ha Viverda + 1.0 l/ha Ultimate S, GS 37-39 / 0.6 l/ha Bell + 0.3 l/ha Proline EC 250, GS 55-61 (costs = 9.16 hkg/ha); CPO = Crop Protection Online.

Control strategies in different winter barley cultivars

In 4 winter barley cultivars 5 different control strategies including control and CPO were tested. One trial was at Flakkebjerg and one at LMO. The treatments given below were tested in the two trials. The treatments recommended by CPO are shown in Table 3, and results from the two trials are shown in Table 4.

1. Untreated
2. 0.35 l/ha Prosaro EC 250 / 0.5 l/ha Viverda + 0.5 l/ha Ultimate S (GS 32 & GS 51)
3. 0.75 l/ha Viverda + 0.75 l/ha Ultimate S (GS 37-39)
4. 0.35 l/ha Prosaro EC 250 / 0.5 l/ha Propulse SE 250 + 0.3 l/ha Comet Pro (GS 32 & GS 51)
5. CPO

Table 3. Treatments applied following recommendations from CPO (18351-1 and 18351-2).

Cultivars (18351-1)	Date	Products	TFI	Costs, hkg/ha
Frigg	04-05-2018 18-05-2018	Comet Pro + Propulse SE 250 0.23 + 0.22 Comet Pro + Propulse SE 250 0.3 + 0.32	0.19 + 0.25 0.25 + 0.36	1.07 2.09
Wootan	04-05-2018 18-05-2018	Comet Pro + Propulse SE 250 0.22 + 0.21 Comet Pro + Propulse SE 250 0.3 + 0.32	0.18 + 0.25 0.25 + 0.36	1.59 2.09
Matros	04-05-2018 18-05-2018	Comet Pro + Propulse SE 250 0.21 + 0.2 Comet Pro + Propulse SE 250 0.3 + 0.32	0.17 + 0.23 0.25 + 0.36	1.54 2.09
KWS Infinity	04-05-2018 18-05-2018	Comet Pro + Propulse SE 250 0.18 + 0.19 Comet Pro + Propulse SE 250 0.3 + 0.32	0.15 + 0.22 0.25 + 0.36	1.44 2.09

Cultivars (18351-2)	Date	Products	TFI	Costs, hkg/ha
Frigg	22-05-2018	Comet Pro + Propulse SE 250 0.3 + 0.28	0.24 + 0.32	1.98
Wootan	07-05-2018	Comet Pro + Propulse SE 250 0.22 + 0.26	0.18 + 0.30	1.73
Matros	07-05-2018	Comet Pro + Prosaro EC 250 0.16 + 0.12	0.13 + 0.13	1.18
KWS Infinity	22-05-2018	Comet Pro + Propulse SE 250 0.25 + 0.28	0.2 + 0.32	1.86

Table 4. Control of diseases in winter barley and yield responses from 2 trials in 4 winter barley cultivars using 4 different strategies (18351). (Continues on the next page).

Cultivars (18351)	% brown rust, leaf 2, GS 61/69					% *Rhynchosporium*, leaf 2, GS 61/69				
	Untr.	0.35 Prosaro / 0.5 Viverda + 0.5 Ultimate S	0.75 Viverda + 0.75 Ultimate S	0.35 Prosaro / 0.5 Propulse + 0.3 Comet Pro	CPO	Untr.	0.35 Prosaro / 0.5 Viverda + 0.5 Ultimate S	0.75 Viverda + 0.75 Ultimate S	0.35 Prosaro / 0.5 Propulse + 0.3 Comet Pro	CPO
Frigg	1.3	0.0	0.2	0.0	0.4	25.0	8.0	3.9	9.0	16.7
Wootan	17.3	3.0	1.3	1.4	6.9	3.2	0.9	0.3	0.6	2.3
Matros	5.0	0.4	0.4	0.5	1.2	11.3	1.6	1.2	1.4	3.8
KWS Infinity	1.0	1.1	1.0	0.5	2.9	11.2	3.4	3.7	4.4	9.4
Average	6.2	1.1	0.7	0.6	2.9	12.7	3.5	2.3	3.9	8.1
No. of trials			2					2		

Cultivars (18351)	% net blotch, leaf 2-3, GS 61					% green leaf area, leaf 2, GS 73/87				
	Untr.	0.35 Prosaro / 0.5 Viverda + 0.5 Ultimate S	0.75 Viverda + 0.75 Ultimate S	0.35 Prosaro / 0.5 Propulse + 0.3 Comet Pro	CPO	Untr.	0.35 Prosaro / 0.5 Viverda + 0.5 Ultimate S	0.75 Viverda + 0.75 Ultimate S	0.35 Prosaro / 0.5 Propulse + 0.3 Comet Pro	CPO
Frigg	2.3	1.0	1.0	0.7	2.3	6.7	33.4	18.4	32.5	28.4
Wootan	1.7	1.7	1.7	2.0	3.0	2.2	21.5	12.0	21.7	10.4
Matros	13.3	5.3	6.3	4.3	8.3	1.2	29.2	17.5	31.7	20.0
KWS Infinity	1.7	0.7	0.3	0.3	1.7	5.4	26.7	16.2	29.2	26.2
LSD_{95}			4.4							
Average	4.8	2.2	2.3	1.8	3.8	3.9	27.7	16.0	28.8	21.3
No. of trials			1					2		

Table 4. Control of diseases in winter barley and yield responses from 2 trials in 4 winter barley cultivars using 4 different strategies (18351). (Continued).

Cultivars (18351)	Yield and increase, hkg/ha					Net increase, hkg/ha				TGW				
	Untr.	0.35 Prosaro / 0.5 Viverda + 0.5 Ultimate S	0.75 Viverda + 0.75 Ultimate S	0.35 Prosaro / 0.5 Propulse + 0.3 Comet Pro	CPO	0.35 Prosaro / 0.5 Viverda + 0.5 Ultimate S	0.75 Viverda + 0.75 Ultimate S	0.35 Prosaro / 0.5 Propulse + 0.3 Comet Pro	CPO	Untr.	0.35 Prosaro / 0.5 Viverda + 0.5 Ultimate S	0.75 Viverda + 0.75 Ultimate S	0.35 Prosaro / 0.5 Propulse + 0.3 Comet Pro	CPO
Frigg	63.7	6.0	6.3	7.7	4.2	1.7	3.4	3.8	1.6	40.1	22.6	40.1	40.9	39.5
Wootan	66.2	2.2	6.5	5.7	4.7	-2.1	3.6	1.8	2.0	35.7	36.6	38.1	36.4	37.4
Matros	60.9	8.8	4.9	8.9	5.9	4.5	2.0	5.0	3.5	37.2	39.0	38.9	38.5	39.9
KWS Infinity	64.7	3.9	6.2	8.0	7.7	-0.4	1.0	4.1	5.0	41.0	41.4	41.8	41.6	41.0
Average	63.9	5.2	6.0	7.6	5.6	0.9	2.5	3.7	3.0	38.5	34.9	39.7	39.4	39.5
No. of trials			2				2					2		

Untr. = Untreated; 0.35 l/ha Prosaro EC 250, GS 32 / 0.5 l/ha Viverda + 0.5 l/ha Ultimate S, GS 51 (costs = 4.3 hkg/ha); 0.75 l/ha Viverda + 0.75 l/ha Ultimate S, GS 37-39 (costs = 2.9 hkg/ha); 0.35 l/ha Prosaro EC 250, GS 32 / 0.5 l/ha Propulse SE 250 + 0.3 l/ha Comet Pro, GS 51 (costs = 3.9 hkg/ha); CPO = Crop Protection Online.

Control of strategies in different spring barley cultivars

In 5 spring barley cultivars 4 different control strategies including control and CPO were tested. One trial was placed at Flakkebjerg and one at LMO. The treatments given below were tested in the two trials. The treatments recommended by CPO are shown in Table 5, and results from the two trials are shown in Tables 6 and 7.

1. Untreated
2. 0.25 l/ha Prosaro EC 250 / 0.5 l/ha Viverda + 0.5 l/ha Ultimate S (GS 31 & GS 51)
3. 0.75 l/ha Viverda + 0.75 l/ha Ultimate S (GS 37-49)
4. 0.25 l/ha Prosaro EC 250 / 0.5 l/ha Propulse SE 250 + 0.3 l/ha Comet Pro (GS 31 & GS 51)
5. CPO

Table 5. Treatments applied following recommendations from CPO (18352-1 and 18352-2).

Cultivars (18352-1	Date	Products, l/ha	TFI	Costs, hkg/ha
Propino	23-05-2018	Propulse SE 250 + Comet Pro 0.15 + 0.15	0.29	1.26
Laurikka	29-05-2018	Propulse SE 250 + Comet Pro 0.38 + 0.26	0.64	2.15
Evergreen	-	-	-	-
KWS Irina	29-05-2018	Propulse SE 250 + Comet Pro 0.38 + 0.26	0.64	2.15

No treatments were applied at LMO.

Again only the trial at Flakkebjerg provided useable disease data as the LMO trial suffered significantly from drought. The trial at Flakkebjerg was irrigated twice and developed a very severe attack of brown rust and a minor attack of net blotch. The attack led to treatments in 3 of the 4 cultivars using CPO. The dose rates applied using CPO did not provide sufficient late control, but did still provide enough control to not make yields suffer.

Generally, double treatments performed better than one treatment and Viverda performed similarly to Propulse SE 250 + Comet Pro. Although positive, yield responses were generally not significantly different from untreated, but TGW and grain size were positively influenced by treatments.

Table 6. Control of diseases in spring barley and yield responses from 1 trial in 4 different spring barley cultivars using 4 different strategies (18352-1). (Continues on the next page).

Cultivars (18352-1)	% brown rust, leaf 2-3, GS 75					% brown rust, leaf 2, GS 83				
	Untr.	0.25 Prosaro / 0.5 Viverda + 0.5 Ultimate S	0.75 Viverda + 0.75 Ultimate S	0.25 Prosaro / 0.5 Propulse + 0.3 Comet Pro	CPO	Untr.	0.25 Prosaro / 0.5 Viverda + 0.5 Ultimate S	0.75 Viverda + 0.75 Ultimate S	0.25 Prosaro / 0.5 Propulse + 0.3 Comet Pro	CPO
Propino	20.0	2.0	1.2	1.8	9.0	63.3	2.2	7.7	4.4	60.0
Laurikka	15.0	3.8	0.7	2.2	1.0	55.0	2.2	0.4	3.0	1.0
Evergreen	11.7	0.7	0.9	0.5	14.0	60.0	0.2	0.7	0.4	63.3
KWS Irina	17.3	0.9	2.0	0.8	2.5	53.3	0.5	8.3	4.7	13.3
LSD_{95}	5.1					20.8				
Average	16.0	1.9	1.2	1.3	6.6	57.9	1.3	4.3	3.1	34.4
No. of trials	1					1				

Table 6. Control of diseases in spring barley and yield responses from 1 trial in 4 different spring barley cultivars using 4 different strategies (18352-1). (Continued).

Cultivars (18352-1)	% net blotch, leaf 2-4, GS 59					% net blotch, leaf 2-4, GS 75				
	Untr.	0.25 Prosaro / 0.5 Viverda + 0.5 Ultimate S	0.75 Viverda + 0.75 Ultimate S	0.25 Prosaro / 0.5 Propulse + 0.3 Comet Pro	CPO	Untr.	0.25 Prosaro / 0.5 Viverda + 0.5 Ultimate S	0.75 Viverda + 0.75 Ultimate S	0.25 Prosaro / 0.5 Propulse + 0.3 Comet Pro	CPO
Propino	4.3	1.7	0.7	3.7	1.3	8.3	1.7	1.2	3.7	2.3
Laurikka	1.0	0.4	0.2	0.2	0.0	1.5	0.9	0.2	0.3	0.0
Evergreen	0.8	0.2	0.0	0.3	0.2	1.3	0.2	0.1	0.2	2.0
KWS Irina	0.3	0.5	0.0	0.1	0.0	1.0	0.5	0.2	0.1	0.0
LSD_{95}	1.3					1.8				
Average	1.6	0.7	0.2	1.1	0.4	3.0	0.8	0.4	1.1	1.1
No. of trials	1					1				

Cultivars (18352-1)	Grain > 2.8					TGW g/1000				
	Untr.	0.25 Prosaro / 0.5 Viverda + 0.5 Ultimate S	0.75 Viverda + 0.75 Ultimate S	0.25 Prosaro / 0.5 Propulse + 0.3 Comet Pro	CPO	Untr.	0.25 Prosaro / 0.5 Viverda + 0.5 Ultimate S	0.75 Viverda + 0.75 Ultimate S	0.25 Prosaro / 0.5 Propulse + 0.3 Comet Pro	CPO
Propino	93.1	96.8	95.3	96.0	95.5	55.2	58.2	57.2	57.6	58.4
Laurikka	73.4	82.3	82.3	78.6	84.3	49.7	50.9	51.2	50.8	50.8
Evergreen	92.3	94.4	93.4	91.7	92.6	53.0	52.8	53.7	54.1	52.8
KWS Irina	86.5	90.4	92.2	92.7	93.5	52.1	53.9	54.0	54.9	54.9
LSD_{95}						1.9				
Average	86.3	90.9	90.8	89.8	91.5	52.5	54.0	54.0	54.4	54.2

Cultivars (18352-1)	Yield and increase, hkg/ha					Net increase, hkg/ha			
	Untr.	0.25 Prosaro / 0.5 Viverda + 0.5 Ultimate S	0.75 Viverda + 0.75 Ultimate S	0.25 Prosaro / 0.5 Propulse + 0.3 Comet Pro	CPO	0.25 Prosaro / 0.5 Viverda + 0.5 Ultimate S	0.75 Viverda + 0.75 Ultimate S	0.25 Prosaro / 0.5 Propulse + 0.3 Comet Pro	CPO
Propino	53.5	3.6	5.2	2.2	7.7	0.4	2.3	-1.5	6.4
Laurikka	64.9	-1.3	2.4	0.7	2.4	-4.5	-0.5	-3.0	0.3
Evergreen	55.3	4.7	5.8	6.5	6.4	1.5	2.9	2.8	6.4
KWS Irina	62.0	2.4	0.3	0.0	2.2	-0.8	-2.6	-3.7	0.1
LSD_{95}	4.5					4.5			
Average	58.9	2.4	3.4	2.4	4.7	-0.9	-0.5	-1.4	3.3
No. of trials	1					1			

Untr. = Untreated; 0.25 l/ha Prosaro EC 250, GS 31 / 0.5 l/ha Viverda + 0.5 l/ha Ultimate S, GS 51 (costs = 3.2 hkg/ha); 0.75 l/ha Viverda + 0.75 l/ha Ultimate S, GS 37-49 (costs = 2.9 hkg/ha); 0.25 l/ha Prosaro EC 250, GS 31 / 0.5 l/ha Propulse SE 250 + 0.3 l/ha Comet Pro, GS 51 (costs = 3.7 hkg/ha); CPO = Crop Protection Online.

Table 7. Yield responses from trial 18352-2 in spring barley (LMO).

Cultivars (18352-2)	Yield and increase, hkg/ha					Net increase, hkg/ha			
	Untr.	0.25 Prosaro / 0.5 Viverda + 0.5 Ultimate S	0.75 Viverda + 0.75 Ultimate S	0.25 Prosaro / 0.5 Propulse + 0.3 Comet Pro	CPO	0.25 Prosaro / 0.5 Viverda + 0.5 Ultimate S	0.75 Viverda + 0.75 Ultimate S	0.25 Prosaro / 0.5 Propulse + 0.3 Comet Pro	CPO
Propino	50.1	1.1	1.9	3.0	0.8	-2.1	-1.0	-0.7	0.8
Laurikka	56.8	0.1	1.2	2.3	-1.2	-3.1	-1.7	-1.4	-1.2
Evergreen	56.0	-0.1	0.5	-0.9	-1.4	-3.3	-2.4	-4.6	-1.4
KWS Irina	53.2	1.1	0.9	0.6	-1.2	-2.1	-2.0	-3.1	-1.2
LSD_{95}	5.4					5.4			
Average	54.0	0.6	1.1	1.3	-0.8	-2.7	1.8	-2.5	-0.8
No. of trials	1					1			

Untr. = Untreated; 0.25 l/ha Prosaro EC 250, GS 31 / 0.5 l/ha Viverda + 0.5 l/ha Ultimate S, GS 51 (costs = 3.2 hkg/ha); 0.75 l/ha Viverda + 0.75 l/ha Ultimate S, GS 37-49 (costs = 2.9 hkg/ha); 0.25 l/ha Prosaro EC 250, GS 31 / 0.5 l/ha Propulse SE 250 + 0.3 l/ha Comet Pro, GS 51 (costs = 3.7 hkg/ha); CPO = Crop Protection Online.

IV Fungicide resistance-related investigations

Thies Marten Heick, Lise Nistrup Jørgensen, Hanne-Birgitte Christiansen & Birgitte Boyer Frederiksen

Fungicide resistance of *Zymoseptoria tritici* in Denmark and Sweden

Azole resistance of the fungal wheat pathogen *Zymoseptoria tritici* (*Z. tritici*) in Denmark and Sweden has been tested *in vitro* to survey sensibility of the North European *Z. tritici* populations. The first active ingredient to be tested was epoxiconazole, later prothioconazole, which was replaced by prothioconazole-desthio in 2016. From 2018, the SDHI fluxapyroxad is included in the testing. Each year, diseased leaf samples at growth stage 73-77 are collected in collaboration with SEGES, Jordbruks-verket in Sweden and local advisors and sent to Flakkebjerg. A total of 155 Danish isolates from 24 sites and 127 Swedish isolates from 16 sites were investigated for sensitivity to epoxiconazole, prothio-desthio and fluxapyroxad in 2018. The aim was 10 isolates per site, which was difficult to achieve due to the low disease pressure in 2018.

Microtitre testing *in vitro* was carried out according to the FRAC protocol for DMI sensitivity testing of *Z. tritici* (http://www.frac.info/monitoring-methods). The individual pycnidium isolates were used to produce spore suspensions by scraping off six-day-old *Z. tritici* spores and transferring them into Milli-Q water. Spore suspensions were homogenised and adjusted to a spore concentration of 2.4 x 10^4 spores ml^{-1}. Technical duplicates of each isolate were included in the study. Stock solutions of all three fungicides were made by dissolving the active ingredients (Sigma) in 80% ethanol. Those stock solutions were then utilised to prepare 2 x potato dextrose broth (PDB) mixtures to obtain the following final microtitre plate fungicide concentrations (ppm): 30, 10, 3.3, 1.0, 0.3, 0.1, 0.33, 0 (epoxiconazole), 6.0, 2.0, 0.6, 0.2, 0.07, 0.008, 0.002, 0 (prothioconazole-desthio) and 3.0, 1.0, 0.3, 0.1, 0.03, 0.01, 0.0033, 0 (fluxapyroxad). A total of 100 µl of spore suspension and 100 µl of fungicide solution were added to 96-deep well microtitre plate. Microtitre plates were wrapped in tinfoil and incubated at 20°C for six days in the dark. Plates were visually analysed in an Elisa reader at 620 nm. Fungicide sensitivities were calculated as the concentration of a fungicidal compound, at which fungal growth *in vitro* is inhibited by 50% (EC_{50}) by a non-linear regression (curve fit) using GraphPad Prism (GraphPad software, La Jolla, CA, USA). The isolates IPO323 and OP15.1 were used as reference isolates.

Results - *Denmark*

A significant fungicide sensitivity shift took place from 2017 to 2018 (Figure 1). The average EC_{50} value for epoxiconazole was 5.82 (2016: 1.39 ppm; 2017: 1.81 ppm; Table 1), almost all isolates tested having an EC_{50} value of over 1 ppm. A total of 30 of the 155 isolates tested had an EC_{50} of > 10 ppm. The average resistance factor (RF) for epoxiconazole, as compared to the reference isolate IPO 323, was 215, compared to 94 in 2017. Isolates with high EC_{50} values were found at all sites (Table 2).

Prothioconazole-desthio has been included in the testing since 2016 to replace prothioconazole. The average EC_{50} value for Danish isolates was 0.36 ppm, which was in line with the results in 2018 (Figure 2; Table 1). The RF for prothioconazole-desthio was 36 compared to 32 in the year before. It is hard to compare results for prothioconazole from previous years as there are no clear correlations between those two chemical compounds. Furthermore, there was no clear cross-resistance between epoxiconazole and prothioconazole-desthio in previous years. After the significant change of azole sensitivity in 2018, this is slowly changing. However, in 2018 11 isolates showed high EC_{50} values for prothioconazole-desthio and epoxiconazole. For the first time, all isolates were tested for SDHI fluxapyroxad. The average EC_{50} value was 0.26 ppm, corresponding to a resistance factor of 2.

Table 1. Summary of measured EC_{50} (ppm) values and resistance factors (RF) for epoxiconazole and prothioconazole-desthio and fluxapyroxad assessed for *Z. tritici* in Denmark. Total numbers of tested isolates are given in brackets. Prothioconazole has been discontinued since 2017 (results not shown).

Year	EC_{50} epoxiconazole	RF	EC_{50} prothio-desthio	RF	EC_{50} fluxapyroxad	RF
2005	0.12 (47)	2	-	-	-	-
2006	0.57 (180)	10	-	-	-	-
2007	0.77 (140)	13	-	-	-	-
2008	0.17 (88)	3	-	-	-	-
2009	0.70 (96)	12	-	-	-	-
2010	1.40 (54)	23	-	-	-	-
2011	1.33 (85)	22	-	-	-	-
2012	0.30 (40)	15	-	-	-	-
2013	0.36 (133)	18	-	-	-	-
2014	0.50 (290)	25	-	-	-	-
2015	0.45 (262)	17	-	-	-	-
2016	1.39 (220)	66	0.13 (26)	17	-	-
2017	1.81 (272)	94	0.32 (263)	32	-	-
2018	5.82 (155)	215	0.36 (155)	36	0.26 (155)	2
Ref. IPO323	0.02-0.03	-	0.01	-	0.15	-

Table 2. Results from individual sites with data from sensitivity testing for *Zymoseptoria tritici* screened on epoxiconazole, prothioconazole-desthio and fluxapyroxad.

Location		Number	Epoxiconazole		Prothio-desthio		Fluxapyroxad	
			Average	RF	Average	RF	Average	RF
18-ZT-DK-01	Flakkebjerg	20	4.55	182	0.29	29	0.16	1
18-ZT-DK-02	Horsens,LMO	18	6.94	278	0.72	72	0.35	3
18-ZT-DK-03	Flakkebjerg	19	4.58	183	0.27	27	0.11	1
18-ZT-DK-04	Flakkebjerg	20	3.90	156	0.23	23	0.19	1
18-ZT-DK-07	Kolding	4	4.94	197	0.52	52	0.28	2
18-ZT-DK-10	Flakkebjerg	2	5.78	231	0.22	22	0.14	1
18-ZT-DK-12	Aabenraa	2	3.28	131	0.56	56	0.21	2
18-ZT-DK-13	Aabenraa	2	6.32	253	0.16	16	0.20	2
18-ZT-DK-14	Årslev	3	9.34	374	0.38	38	0.20	2
18-ZT-DK-15	Sønderborg	6	11.12	445	0.36	36	0.99	8
18-ZT-DK-16	Fåborg	2	12.16	486	0.25	25	0.20	2
18-ZT-DK-17	Ebberup	1	9.43	377	0.35	35	0.39	3
18-ZT-DK-18	Esbjerg	1	1.99	80	0.04	4	0.12	1
18-ZT-DK-19	Foulum	6	3.30	132	0.14	14	0.13	1
18-ZT-DK-20	Hobro	1	1.68	67	0.02	2	0.13	1
18-ZT-DK-21	Holeby	2	5.36	214	0.25	25	0.15	1
18-ZT-DK-22	Holeby	4	3.25	130	0.24	24	0.20	2
18-ZT-DK-25	Skive	10	4.00	160	0.14	14	0.25	2
18-ZT-DK-26	Vojens	2	2.22	89	0.29	29	0.19	1
18-ZT-DK-27	Vojens	5	12.09	484	1.07	107	0.75	6
18-ZT-DK-28	Horsens	1	3.15	126	0.37	37	0.07	1
18-ZT-DK-29	Flakkebjerg	10	5.72	229	0.29	29	0.22	2
18-ZT-DK-30	Flakkebjerg	6	7.57	303	1.24	124	0.36	3
18-ZT-DK-31	Ullerslev	8	4.22	169	0.16	16	0.29	2
Reference IPO323		-	0.02	-	0.01	-	0.15	-
Total		155	-	-	-	-	-	-

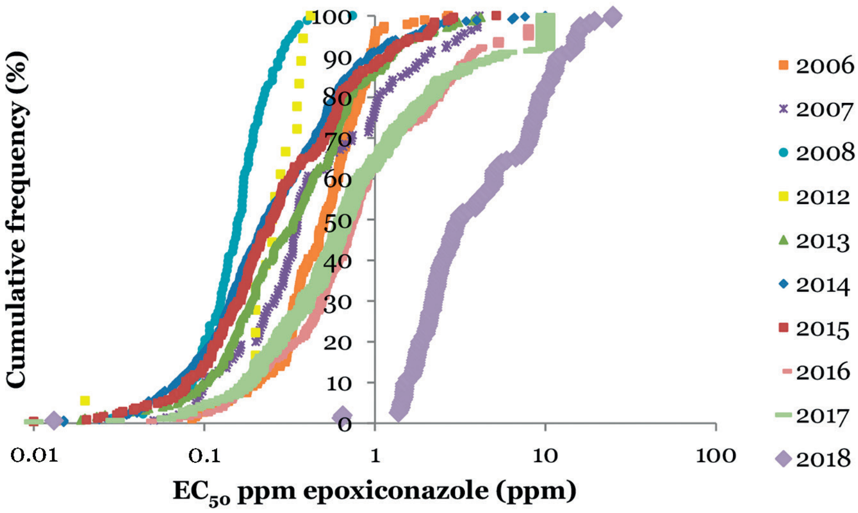

Figure 1. Cumulative frequencies of EC_{50} values of epoxiconazole (ppm) for Danish *Z. tritici* populations 2006-2018.

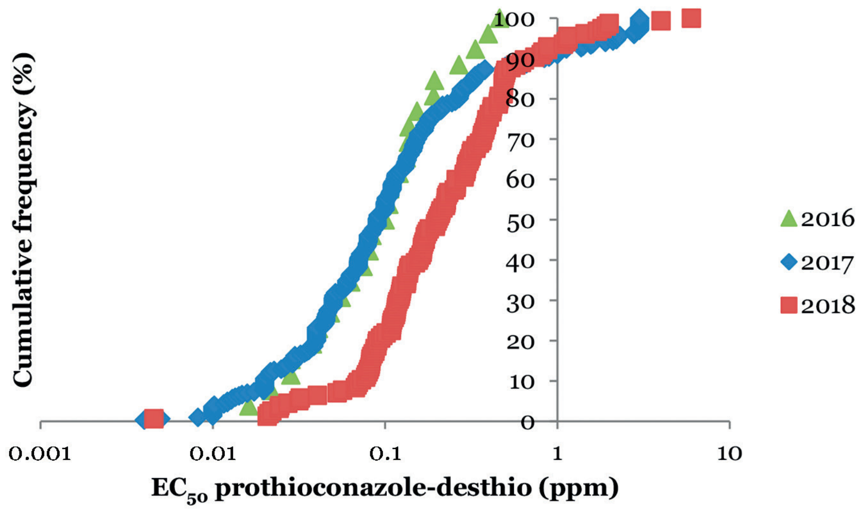

Figure 2. Cumulative frequencies of EC_{50} values of prothioconazole-desthio (ppm) for Danish *Z. tritici* populations 2016-2018.

Results - *Sweden*

After a significant shift in EC_{50} values for epoxiconazole having taken place in 2017, the sensitivity towards this active ingredient continued to increase in 2018 (Table 3). The average EC_{50} value for epoxiconazole was 4.53 ppm (2017: 3.17 ppm). Figure 3 illustrates the shifting of EC_{50} values for epoxiconazole of the Swedish *Z. tritici* population from 2014 to 2018. Most isolates had an EC_{50} over 1 ppm; nine of these values were above 10 ppm (Figure 3). Whereas in previous years there was a clear difference for sites in Middle and Southern Sweden, the shifts which occurred in 2017 and again in 2018 appear to have taken place in the entire country (Table 4). EC_{50} values for prothioconazole-desthio were on average at the same level in Sweden as in Denmark with an average of 0.35 ppm, which was lower than in 2017 (Figure 4). Also results for fluxapyroxad were in line with the Danish results (Figure 5).

Table 3. Summary of measured EC_{50} (ppm) values and resistance factors (RF) for epoxiconazole, prothioconazole-desthio and fluxapyroxad assessed for *Z. tritici* in Sweden. Total numbers of tested isolates are shown in brackets.

Year	EC_{50} epoxiconazole	RF	EC_{50} prothio-desthio	RF	EC_{50} fluxapyroxad	RF
2010	0.63 (131)	13	-	-	-	-
2011	1.00 (166)	16	-	-	-	-
2012	0.36 (211)	18	-	-	-	-
2013	0.65 (170)	33	-	-	-	-
2014	0.27 (337)	35	-	-	-	-
2015	0.33 (227)	12	-	-	-	-
2016	0.52 (212)	24	-	-	-	-
2017	3.17 (163)	170	0.58 (150)	58	-	-
2018	4.53 (127)	181	0.35 (127)	35	0.19 (127)	2
Ref. IPO323	0.02-0.03	-	0.01	-	0.15	

Table 4. Results from individual sites in Sweden with data from sensitivity testing for *Z. tritici* screened on epoxiconazole, prothioconazole-desthio and fluxapyroxad.

Location		Number	Epoxiconazole		Prothio-desthio		Fluxapyroxad	
			Average	RF	Average	RF	Average	RF
18-ZT-SW-01	Sandby Gård	19	3.96	158	0.29	29	0.07	1
18-ZT-SW-02	Sandby Gård	20	5.80	232	0.26	26	0.08	1
18-ZT-SW-03	Kölby, Ljungbyholm	9	3.85	154	0.17	17	0.17	1
18-ZT-SW-04	Skälby, Vassmolösa	10	1.97	79	0.06	6	0.10	1
18-ZT-SW-05	Hagby, Vassmolösa	6	3.55	142	0.16	16	0.14	1
18-ZT-SW-06	Vicleby, Färjestaden, Öland	10	3.85	154	0.24	24	0.14	1
18-ZT-SW-07	Bjällerup, Lund	3	3.27	131	0.19	19	0.56	4
18-ZT-SW-08	Borgeby, Bjärred	10	2.73	109	0.14	14	0.32	3
18-ZT-SW-09	Borrby, Simrishamn	3	1.61	64	0.13	13	0.05	1
18-ZT-SW-10	Öved, Sjöbo	1	10.00	400	1.22	122	0.07	1
18-ZT-SW-12	Hagestadborg, Ystad	10	2.16	87	0.38	38	0.17	1
18-ZT-SW-13	Alnarp	2	17.28	691	1.55	155	0.18	1
18-ZT-SW-14	Vinninga 1	8	4.77	191	0.32	32	0.31	2
18-ZT-SW-15	Källby	6	3.04	122	0.15	15	0.22	2
18-ZT-SW-16	Vinninga 2	9	2.46	99	0.16	16	0.22	2
18-ZT-SW-17	Kalmar	1	2.24	90	0.12	12	0.18	1
Reference IPO323		-	0.02	-	0.01	-	0.15	-
Total		127	-	-	-	-	-	-

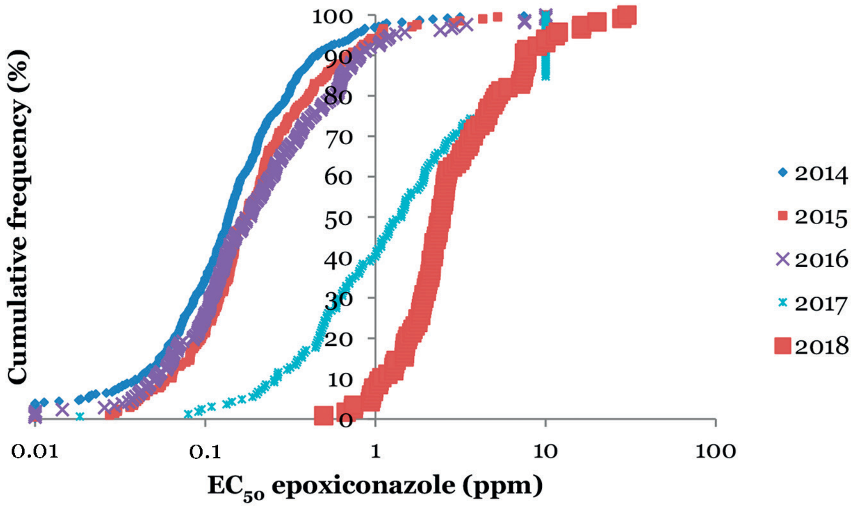

Figure 3. Cumulative frequencies of EC_{50} values of epoxiconazole (ppm) for Swedish *Z. tritici* populations 2014-2018.

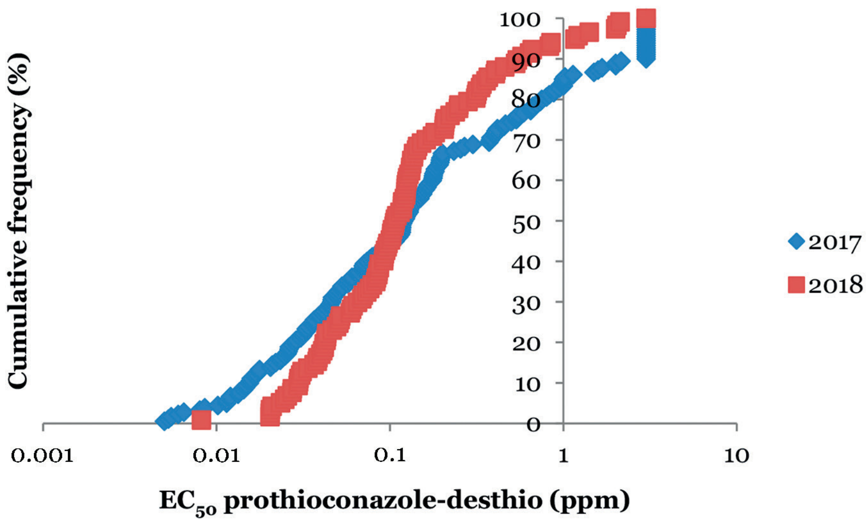

Figure 4. Cumulative frequencies of EC_{50} values of prothioconazole-desthio (ppm) for *Z. tritici* populations in Sweden 2017-2018.

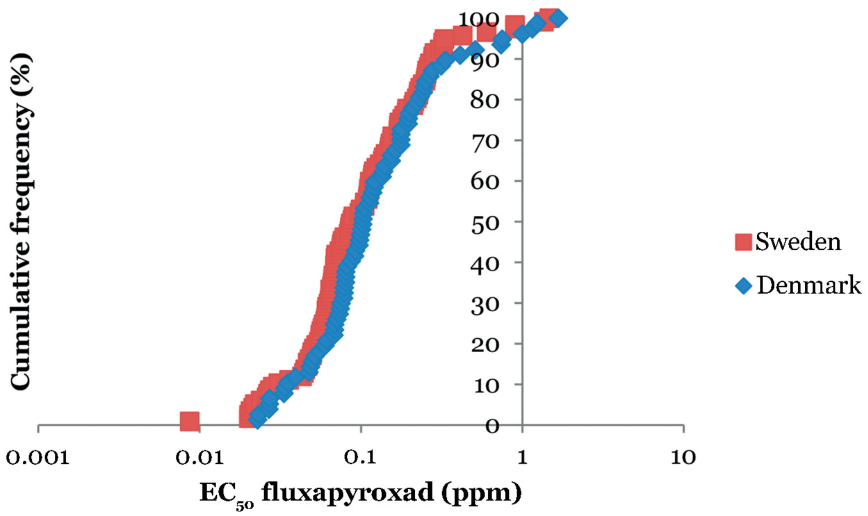

Figure 5. Cumulative frequencies of EC_{50} values of fluxapyroxad (ppm) for *Z. tritici* populations in Denmark and Sweden in 2018.

Sensitivity of difenoconazole, folpet and tebuconazole

A subset of 40 *Z. tritici* isolates from Denmark and Sweden were tested for their sensitivity to the azoles tebuconazole and difenoconazole and the multi-site inhibitor folpet. The resistance level for tebuconazole has been at a high level for many years. In 2018, the average EC_{50} value was 6.21 ppm with single isolates ranging from 0.68 to 27.29 ppm. The average EC_{50} was higher in Denmark (4.46 ppm) than in Sweden (1.91 ppm). The average RF for tebuconazole was 743 (reference isolate IPO323: 0.006 ppm). Those values are in line with results from 2014 when the average EC_{50} for *Z. tritici* from Denmark and Sweden was 2.95 ppm (0.004–17.37 ppm) with an average RF of 737. EC_{50} values for difenoconazole ranged from 0.01 to 1.50 ppm, with an average EC_{50} value of 0.19 ppm and a resistance factor of 34, indicating the presence of slightly adapted isolates in the Scandinavian *Z. tritici* population. No difference was found between Danish and Swedish isolates. Sensitivity towards folpet remains on a high level with RF between 1 and 6.

CYP51 mutations in the *Z. tritici* populations in the Baltic region 2017

The decline of azoles has been associated with molecular changes in the target gene CYP51. In 2018, leaf samples from Denmark, Sweden, Estonia, Finland, Latvia and Lithuania were analysed by sequencing and qPCR (KASP) for the frequency of the most important CYP51 mutations in *Z. tritici*: D134G, V136A/C, I381V and S524T (Table 5). Mutation I381V continued to dominate throughout the region and is present in frequencies of 90-100%. The frequencies for mutations D134G, V136A/C and S524T, all of which have recently emerged in the North European *Z. tritici* population, varied greatly. The evolution of CYP51 mutations in Denmark is illustrated in Figure 6.

Compared to 2017 and recent years, the frequencies in 2018 remain more and less at the same level. *Z. tritici* populations in the Baltic countries and Finland begin more to resemble those in Denmark and Sweden, indicating that the evolution in the CYP51 gene has reached the north-eastern parts of Europe.

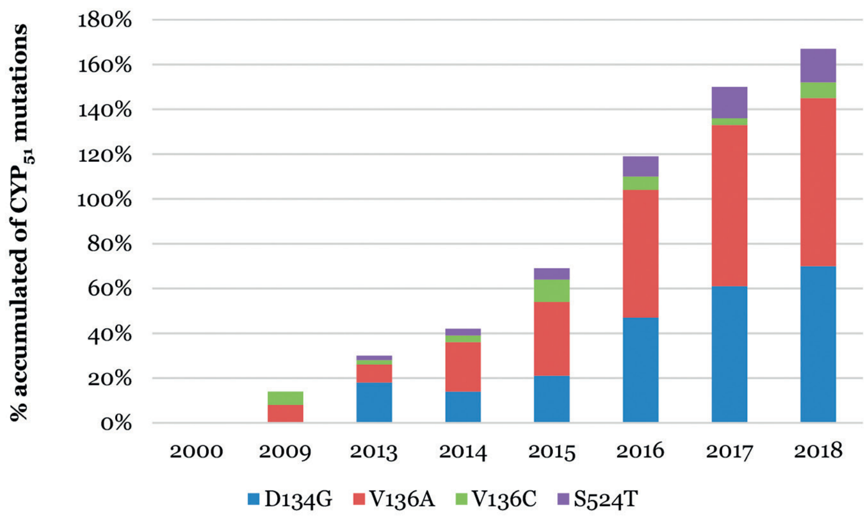

Figure 6. Cumulative frequencies of EC_{50} values of epoxiconazole (ppm) for Danish *Z. tritici* populations 2014-2018.

Table 5. CYP51 mutation frequencies (%) in bulked *Z. tritici* samples from Denmark, Sweden, Estonia, Lithuania, Latvia and Finland.

Baltic Sea area 2018	CYP51					
	D134G	V136A	V136C	A379G	I381V	S524T
Denmark	60%	70%	5%	20%	95%	8%
Sweden	60%	60%	1%	30%	98%	5&
Estonia	10%	25%	3%	24%	98%	10%
Lithuania	19%	25%	6%	26%	100%	10%
Latvia	50%	25%	0%	25%	99%	0%
Finland	30%	30%	0%	30%	88%	0%

Sdh mutations conferring resistance to SDHI fungicides

Several point mutations in the *Sdh* subunits have been associated with elevated EC_{50} values: B-N225I/T, B-H267X, B-T268I, B-I269V, C-N86S, C-N86K, C-T79N, C-T79I, C-W80S, C-G90R and C-H152R. In 2017, three isolates were found in Denmark having the C-T79N mutation. Those were found at Flakkebjerg, in the island of Funen and in Jutland. In 2018, at least one Danish isolate was found with the C-T79N mutation. In Sweden, both in 2017 and 2018, few isolates were tested positive for the presence of the C-N86S mutation. Unlike the CYP51 mutations for the azole group, *Sdh* mutations have not occurred in combination in nature yet.

According to FRAC's minutes, all SDHIs share the same cross-resistance group and ought to be treated with caution with regard to resistance development. SDHIs boscalid (pyridine carboxamide) and fluopyram (pyridinyl-ethyl benzamide) do not belong to the same SDHI subgroup as most SDHIs of the newer generation (pyridine-4-carboxamide). There has thus been some discussion on cross-resistance concerning SDHIs from different subgroups. Figure 7 gives an indication that cross-resistance between these two active ingredients exists to the same degree in a sensitive *Zymoseptoria tritici* population, though not full cross-resistance. Isolates that were included in this study did not have any *Sdh* mutation or MDR, and no other mechanisms such as non-target-site resistance are taken into account.

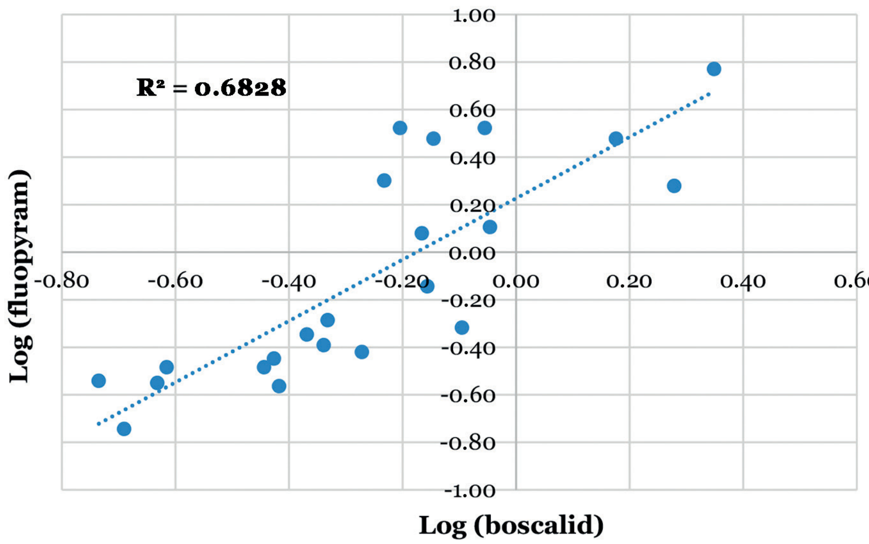

Figure 7. Cross-resistance pattern for the SDHIs boscalid and fluopyram of Danish field isolates from 2018.

V Control of late blight (*Phytophthora infestans*) and early blight (*Alternaria solani*) in potatoes

Bent J. Nielsen, Isaac Kwesi Abuley & Hans Hansen

Methods

The potato trials were carried out at AU Flakkebjerg on sandy clay loam (JB 5-6) with a randomised complete block design and 4 replicates with the starch varieties Kuras and Signum. The plot size was 3.75 x 7 m (26.25 m2) with net yield plots of 15.75 m2. The potatoes were planted on 22-30 April and emerged at the end of May. The late blight trials were artificially inoculated on 26-27 June by spraying 250 ml sporangial suspension of *Phytophthora infestans* (1000 sporangia/ml) over one plant per plot in the spreader rows between the blocks. The plants were covered with a black polythene bag right after the inoculation to ensure free water on the leaves and exclude UV light until the next morning. The early blight trials were artificially inoculated from 14 to 20 June with autoclaved barley seeds inoculated with *Alternaria solani* and *A. alternata* placed in the furrow between the plants. A second inoculation was done on 16 August in some trials by spraying a spore suspension of *A. solani* on plants in the border rows between the plots. All sprayings were carried out according to the protocols, and the spray technique was 300 l water/ha, Hardi ISO MD 025 nozzle and 3 bar. Due to the hot summer in which the trials were carried out, the plants were irrigated 4-6 times with 35 mm of water from mid-June until the end of July. The trials were carried out according to EPPO guidelines PP 1/2(4), PP 1/135(3), PP 1/152(3), PP 1/181(3) and PP 1/263(1).

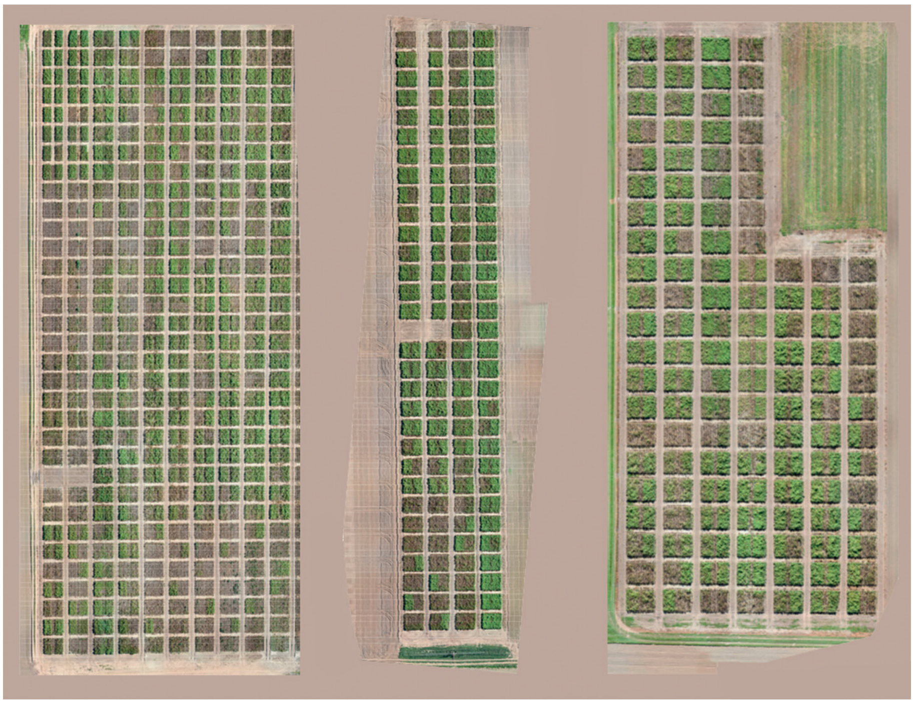

Photo 1. A picture showing the site and plots on which the trials were carried out at Flakkebjerg in 2018. Fields N25 (left), M19 (centre) and N30 (right). (Photo: Uffe Pilegård Larsen).

Potato late blight (*Phytophthora infestans*) in 2018

Untreated plants in the spreader rows between the blocks at Flakkebjerg were inoculated on 26-27 June with a suspension of *P. infestans* sporangia. The first attacks were seen on leaves and stems in the spreader rows on 2 July.

Photo 2. A picture showing the first late blight symptoms on a potato leaf after inoculation. (Photo: Hans Hansen).

Photo 3. Stems attacked by sporulating late blight. (Photo: Hans Hansen).

However, the days after the first symptoms were observed were characterised by high temperatures and low relative humidity. Therefore, the foliar lesions dried up quickly, while the infection and sporulation on the stems continued to grow (see Photo 3).

However, from 16 July these stem attacks also began to dry up and at the end of July they had completely withered. From 11-12 August we witnessed many rainy days as well as moderate to lower temperatures. Accordingly, we saw an increase in the infection risk as predicted by Blight Manager (the Danish decision support system "Skimmelstyring") (Figure 1). Late blight that had been established in the spreader rows after the inoculation on 26 June probably survived in the stems and was now seen sporulating between the withered and green parts of the stems from 13 August. The first airborne attack of late blight was observed in the trials from 21 August (Figure 2).

Periods with high infection pressure were measured 11-16 August and again from 27 August to 10 September (Figure 1).

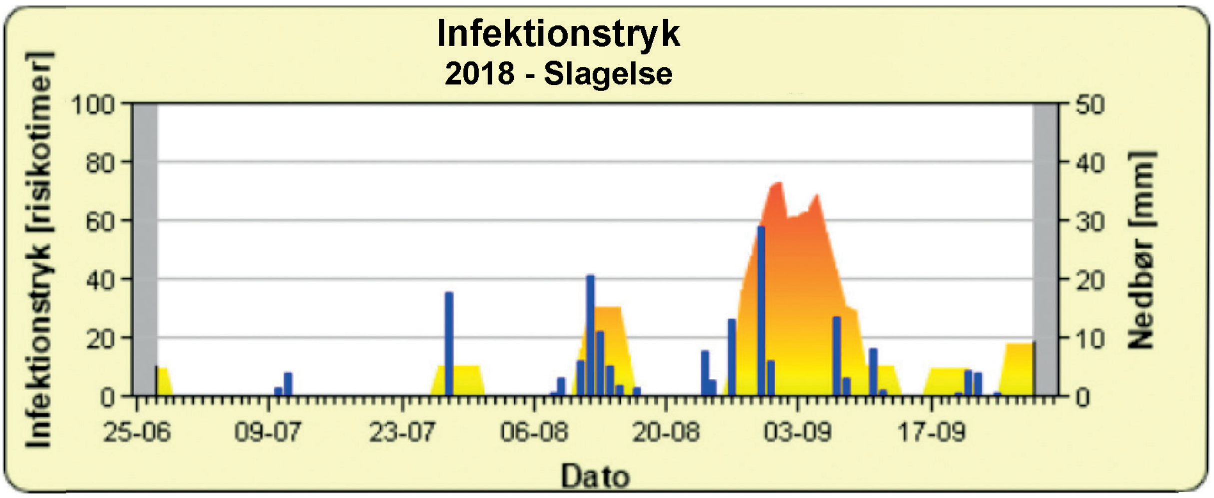

Figure 1. Infection pressure ("Infektionstryk", 5 days running mean) for potato late blight and precipitation (mm) for Slagelse 2018 (10 km north-west of Flakkebjerg). (http://agro.au.dk/ forskning/projekter/skimmelstyring/skimmelstyring-dk-overblik/).

The disease development in 2018 began almost at the same time as in previous years apart from the late (and dry) year 2013. The first symptoms of late blight were observed in the untreated plots at Flakkebjerg on 22 July 2009, 20 July 2010, 15 July 2011, 9 July 2012, 22 July 2013, 16 July 2014, 31 July 2015, 13 July 2016 and 15 July 2017 (Figure 2).

The dry September was not conducive to tuber infections, and thus tuber attacks were limited (0-3%) in all the trials.

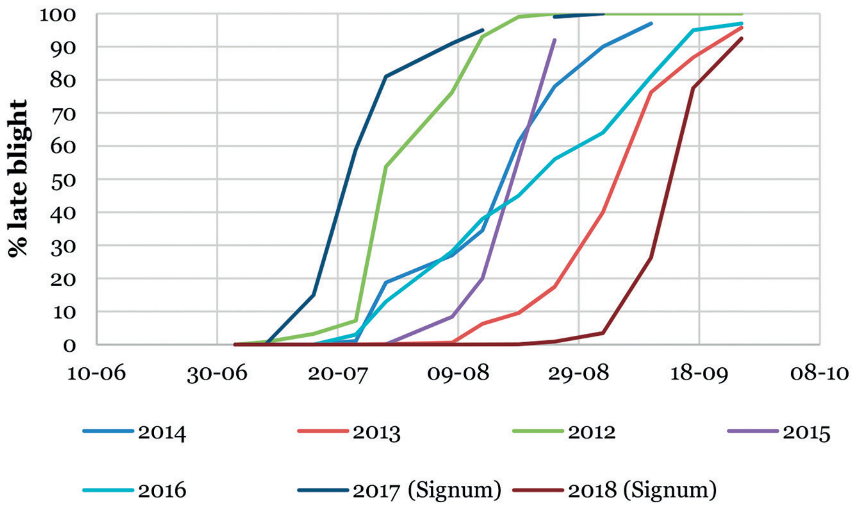

Figure 2. Development of late blight (*Phytophthora infestans*) in untreated plots of varieties Dianella (2012-2014), Eurogrande (2015-2016) and Signum (2017-2018) at Flakkebjerg, 2012-2018. Artificial inoculation was carried out from the end of June to early July.

Potato early blight (*Alternaria solani*) in 2018

The trials at Flakkebjerg were artificially inoculated on 14-20 June 2018 with autoclaved barley seeds inoculated with *A. solani* (seeds were placed in the furrow between the plants). The weather was generally characterised by fewer hours of leaf wetness. Thus, the weather was generally not favourable for disease development. As a result, we inoculated the spreader rows between the blocks again with a conidial suspension of *A. solani* on 16 August. All the isolates of *A. solani* that we used in field N25 (Photo 1) were sensitive to azoxystrobin. In field M19, we used a mixture of mixture of *A. solani* and *A. alternata* (4:1). Six isolates of *A. solani* collected from Jutland in 2016 and 2017 were used in field M19. These six isolates carry the F129L mutation and thus have reduced sensitivity to azoxystrobin.

The first attacks on the lower leaves were detected on 13 July at Flakkebjerg. However, the weather conditions were not favourable for disease development in July due to hot and dry weather. It was not until the first weeks of August (11-12 August) when the first rain came and again from the end of August that conditions for development of early blight improved. In the last part of August and in September, the development was severe with 80-100% attack at the end of September in untreated plots (Figures 3-4).

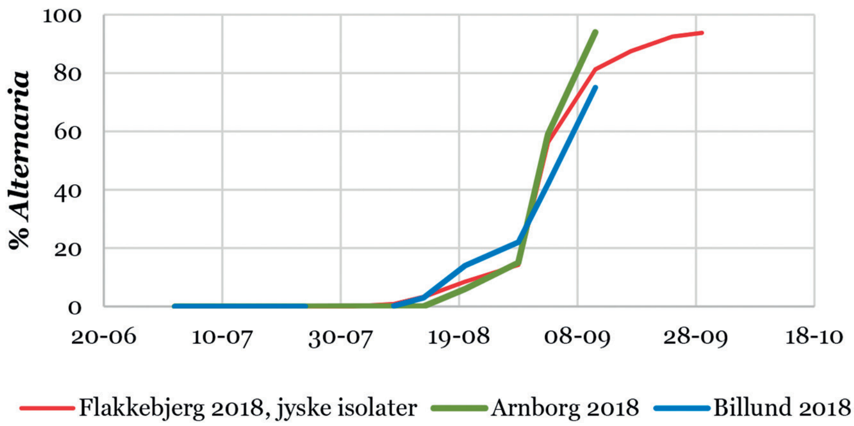

Figure 3. Development of early blight (*Alternaria solani*) in untreated plots at Flakkebjerg, Arnborg (Western Jutland) and Billund (Central Jutland) in 2018. Artificial inoculation at Flakkebjerg with isolates collected in Jutland (F129L isolates, "jyske isolater"), natural infestations at Arnborg and Billund. Variety Kuras.

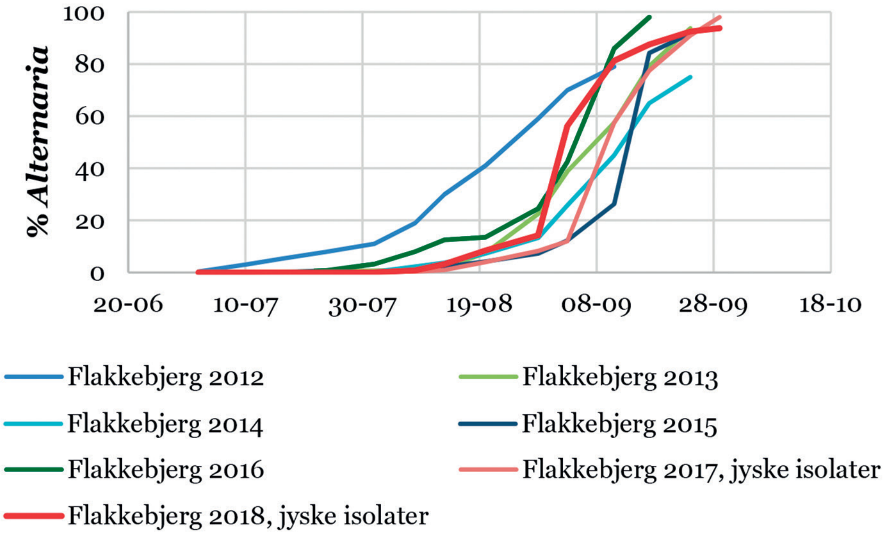

Figure 4. Development of early blight (*Alternaria solani*) in untreated plots at Flakkebjerg from 2012 to 2018. Artificial inoculation with inoculated barley seeds in mid-June (2018) to the end of June. Inoculation 2017 and 2018 with isolates collected in Jutland ("jyske isolater" of F129L type). In 2012-2016 standard ("old") azoxystrobin sensitive isolates were used. Varieties Kuras and in 2015 Kardal.

Photo 4. Severe infections of early blight (*Alternaria solani*) in field plots at the end of the season. (Photo: Isaac Abuley).

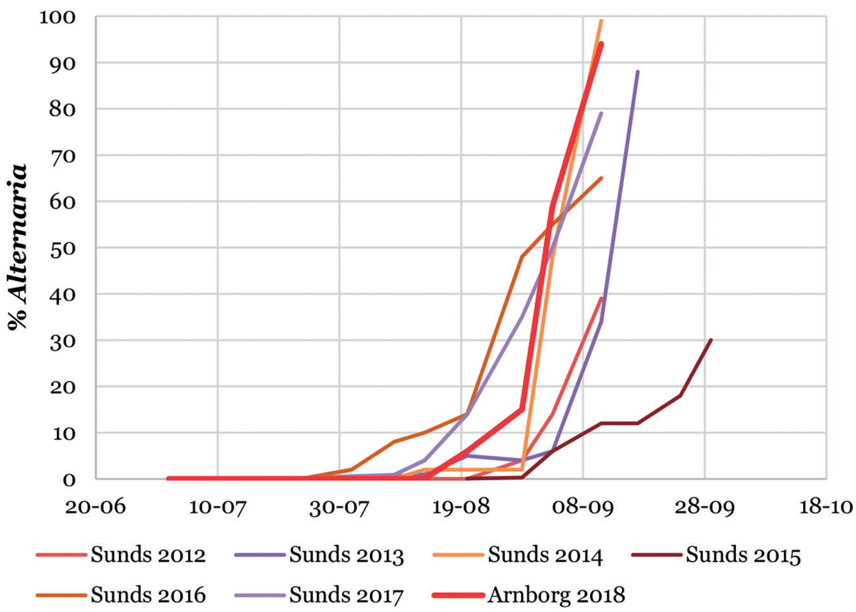

Figure 5. Development of early blight (*Alternaria solani*) in untreated plots at Sunds/Arnborg (Jutland) 2012-2018. Natural infestations. Varieties Kuras and in 2015 Kardal.

The development in early blight at Flakkebjerg in 2018 started almost at the same time as in previous years (Figure 4).

The first symptoms of early blight in the trial at Arnborg (24 km south of Sunds) were seen on 26 July with severe disease development and 94% attack in untreated plots on 11 September (Figure 5). In the trial at Billund, the first symptoms of early blight were seen on 7 August with 75% attack in mid-September (Figure 6). In 2016, the trial at Billund was located in a field where potato was last grown 8 years before.

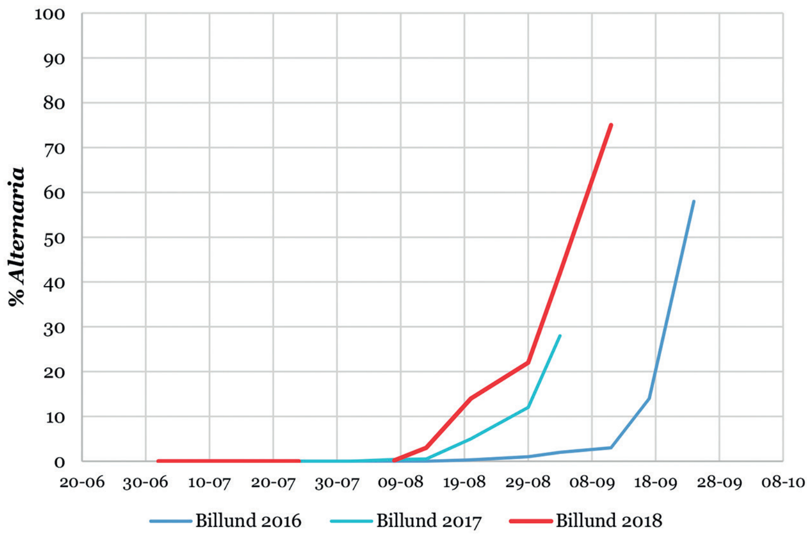

Figure 6. Development of early blight (*Alternaria solani*) in untreated plots at Billund (Central Jutland) 2016-2018. Natural infestations. Variety Kuras.

Early blight development and the weather

Early blight is a disease that is largely influenced by weather and plant age. Thus, models that estimate or predict the favourability of the weather for the disease have an important role in understanding periods that are likely to favour early blight attack. In Denmark, we estimate the plant age as well as the weather factors that favour early blight with epidemiological models. In 2018, we used the physiological days (P-days) model to estimate the plant age of the potatoes we cultivated. This model is similar to the growing degree days model (GDD) in that it estimates the development or age of the potato crop based on temperature. However, the P-days model was strictly developed for the potato crop and thus it is more suited to potatoes than to other plants.

Photo 5. Spore of *Alternaria solani*. (Photo: Isaac Abuley).

Based on the age or developmental stage of the potato crop, the crop may be resistant, moderately susceptible or very susceptible (Abuley and Nielsen, 2017). The potato crop is resistant from crop emergence until tuber initiation or when the crop is 330 P-days old (Abuley and Nielsen, 2017). From tuber initiation or 330 P-days, the crop becomes moderately susceptible to early blight and thus indicates the time when fungicide spraying should be started. The age at which potatoes become very susceptible varies with the maturity period of the potato crop. Early maturing varieties reach the very susceptible stage earlier than late maturing varieties. In Denmark, we see the very susceptible stage at 500 P-days for late maturing varieties (e.g. Kuras). Among the weather factors that affect early blight, temperature and leaf wetness or humidity are very important. Accordingly, we usually monitor these weather factors in our experimental set-ups. As in the past years, we used the TOMCAST DSV model to monitor the favourability of the weather for early blight. Simply put, the TOMCAST DSV model assesses the risk of early blight based on the total hours of leaf wetness and the average temperature during the leaf-wet hours. The risk values or disease severity values (DSV) range from 0, which means no risk of early blight, to 4, which means high risk of early blight attack.

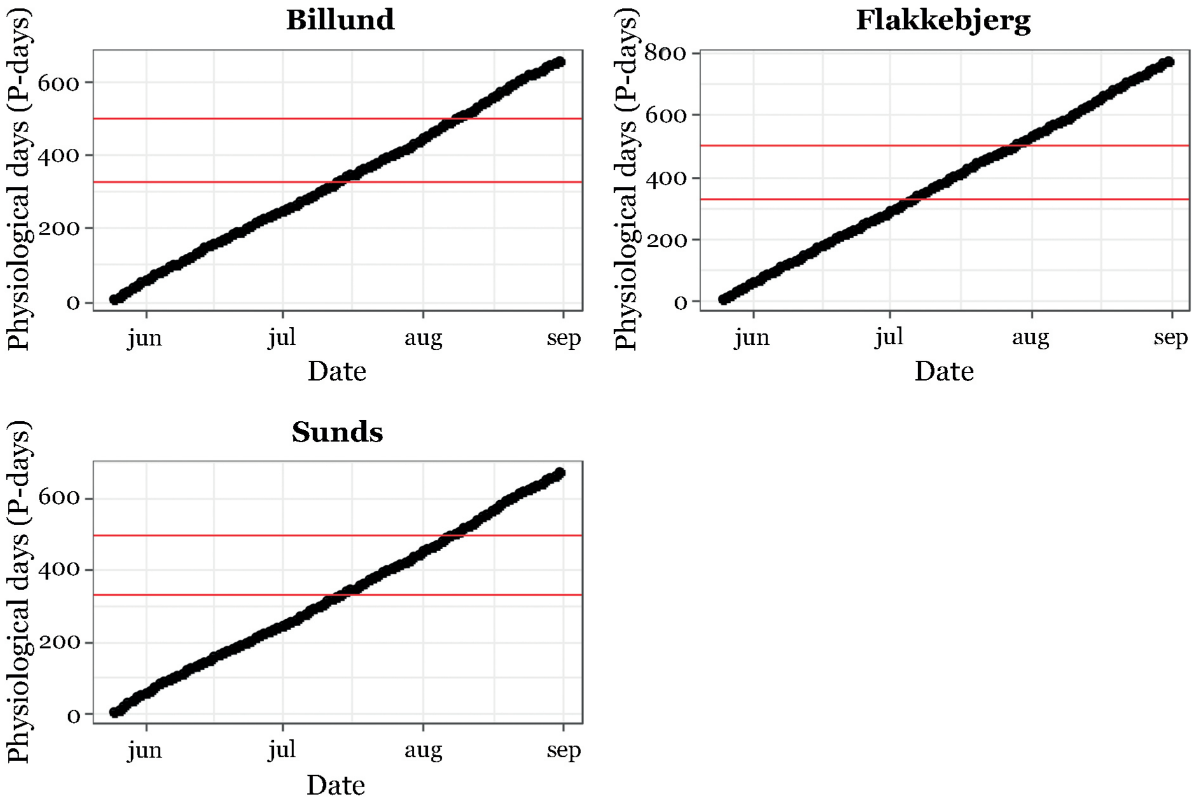

Figure 7. The physiological age of the potatoes (expressed as physiological days [P-days]) estimated from 50% emergence at Flakkebjerg, Billund and Sunds in 2018. The lower and upper red lines represent the 330 and 500 P-days thresholds or age at which potatoes become moderately and very susceptible to early blight, respectively. The 330 P-days were reached on 9 July, 14 July and 14 July at Flakkebjerg, Billund and Sunds, respectively. The 500 P-days were reached on 28 July, 8 August and 8 August at Flakkebjerg, Billund and Sunds, respectively.

Onset of early blight and the P-days model

The 330 P-days threshold at Flakkebjerg, Billund and Sunds occurred on 9 July, 14 July and 14 July, respectively (Figure 7). Our observation from 2018 showed that first early blight lesions were observed on 13 July at Flakkebjerg, 7 August at Billund and 26 July at Sunds. This means than the first symptoms occurred 4 days after the P-days model predicted the beginning of the susceptibility of the potatoes to early blight at Flakkebjerg. In the case of Billund and Sunds, first symptoms occurred 24 and 12 days after the prediction by the P-days model. The apparent delay of the occurrence of first symptoms after the P-days model had predicted the time to expect the first symptoms was mainly because of the dry conditions that characterised the days for most part of July. As will be seen from the TOMCAST model described in the next section, favourable conditions, especially leaf wetness/high humidity, were too poor for infection by *A. solani*, although the plant had reached the susceptibility stage. This suggests that future use of the P-days model should be complemented by weather-based models such as the TOMCAST model.

The TOMCAST model and early blight development

Generally, the daily risk of early blight was moderate in the months of June and July, which were characterised by a daily risk of 0 to 1 (Figure 8). This caused the relatively longer period for cumulative risk of early blight to reach the recommended threshold or peak (20 DSV). This is also evidenced by the relatively restricted or slow development of early blight on the potatoes (Figures 3-6). Rapid development of early blight was observed from the beginning of August for two reasons. First, as illustrated in Figure 7, the potatoes reached the very susceptible stage from the beginning of August. Therefore, the host was very suitable for the pathogen for infection and sporulation. The second reason was that there were several days with daily risk values between 2 and 3 and thus the cumulative risk period was reached more quickly. In other words, the weather was more favourable for early blight and the potato crop was very susceptible from August; hence the increase in the disease development (Figures 3-8).

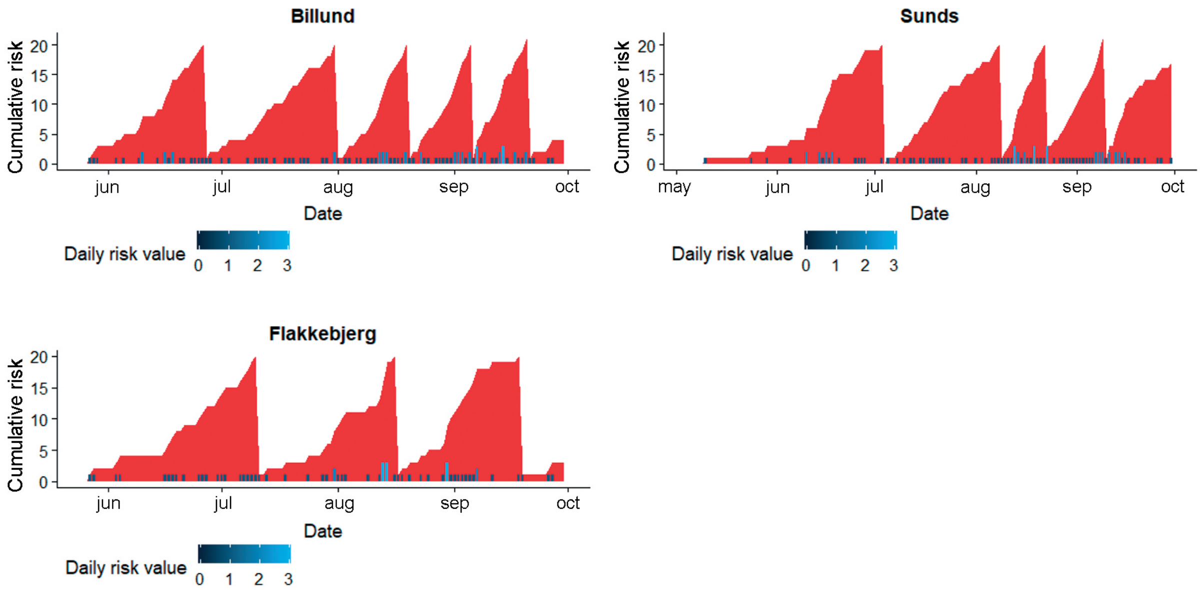

Figure 8. The favourability of the weather for early blight attack estimated by the TOMCAST DSV model at Flakkebjerg, Billund and Sunds in 2018. The red area and bars represent the cumulative and daily risk of early blight attack, respectively. The steeper the red area, the more quickly the daily risks are accumulated and vice versa. The TOMCAST DSV was calculated according to the dew model from the FAST model (Forecasting *Alternaria* of Tomatoes)(Madden et al., 1978) and modified according to Abuley and Nielsen (2017).

Results from field trials 2018

Test of decision support systems and strategies in controlling late blight (*P. infestans*)

In 2018 a trial plan was carried out in cooperation with SEGES to test the efficacy of two decision support systems, Skimmelstyring and Akkerweb, to control potato late blight (Table 1). Also included in the trial were strategies using the fungicides Cymbal 45 (cymoxanil) and Zorvec Enicade (oxathiapiprolin) in high risk periods. The trial plan was carried out at three places in Denmark: Dronninglund, Arnborg (Jutland) and Flakkebjerg (Zealand). Below is a brief description of the two models:

Skimmelstyring is a Danish decision support system that calculates the risk of infection of late blight based on local weather data and recommends different doses of fungicides. The recommendation in Skimmelstyring is only for preventive treatments and includes only two fungicides, Revus and Ranman Top, at a weekly treatment interval (Figure 9).

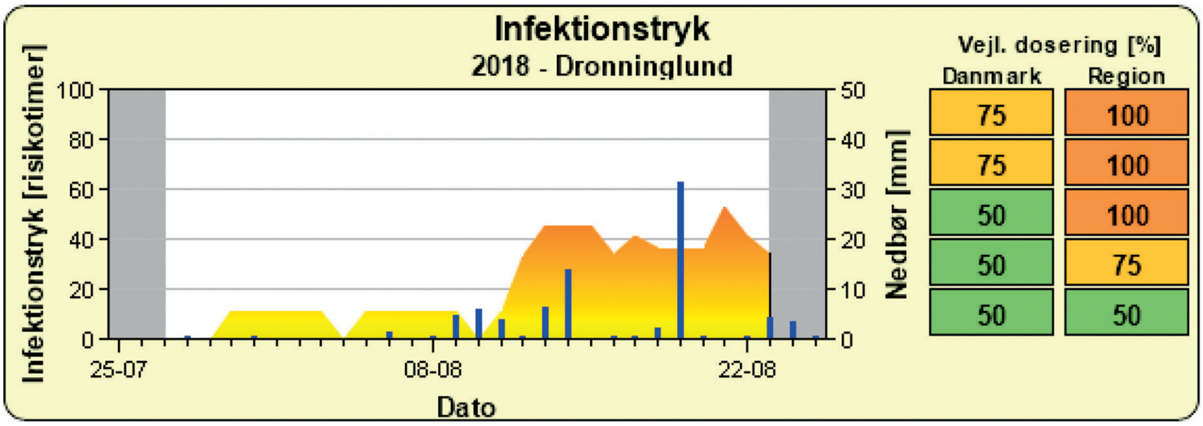

Figure 9. The curves show the infection pressure and the figures to the right show the recommended dose as a percentage of the standard dose of Revus or Ranman Top according to the level of infection pressure in the area. Low risk = < 20, medium risk = 20-40, high risk = 41-60, very high risk = > 60. The recommended dose (% of standard dose) is shown for the early season when late blight is found somewhere in Denmark and later when late blight is found in the region where the field is located. (http://agro.au.dk/forskning/projekter/skimmelstyring/skimmelstyring-dk-overblik/).

Akkerweb is a specific Dutch decision support system developed by Wageningen University together with a private IT company. After filling in field data (variety, sprayings and irrigation) and connecting the program to local weather, the program can calculate when a treatment is needed and which type of fungicide (preventive, curative or eradicative) that will be optimal depending on the infection situation. The program can handle different fields (Figure 10).

Figure 10. Output from the Akkerweb model. On the top, a bar shows day by day a colour which recommends the protection mode in the field. Green = fully protected, yellow = preventive treatment is needed, orange = curative treatment is needed, red = eradicative treatment is needed. (https://akkerweb.eu/en-gb/).

When treatment dose and spray date have been entered, the program calculates the number of days for which the field is expected to be fully protected. After the fully protected period ends, the time for next treatment depends on the calculated risk of infection, based on the weather conditions for spore production and infections.

Table 1 below shows the trial plan and the average results for the three trial sites.

Table 1. Control of late blight using the DSS models Skimmelstyring and Akkerweb together with spray strategies using Cymbal 45 and Zorvec Enicade + Curzate M68 WG. Dose of used products and number of sprays (average for the three trials) are shown. Variety Kuras at Flakkebjerg and Arnborg and variety Signum at Dronninglund. Average results of 3 trials, Flakkebjerg, Arnborg and Dronninglund 2018.

Treat-ment no.	Treatments	Product	Dose	No. of sprayings	Late blight attack % end season	Tuber yield and yield increase hkg per ha	Starch yield and yield increase hkg per ha	Yield and net yield DKK per ha
1	Untreated				44.2	586	110	35053
2	Weekly	Ranman Top	0.5	13	1.9	49	12	472
3	Weekly	Ranman Top	0.25	13	0.5	19	7	82
4	Skimmelstyring	Ranman Top	0.25/0.375/0.5*	13				
4	Skimmelstyring	Cymbal 45	0.25		0.5	19	7	-586
4	Skimmelstyring	Proxanil	2	0.67				
5	Akkerweb preventive	Ranman Top	0.5	6.33				
5	Akkerweb curative	Cymbal 45	0.25	0.67	0.3	39	9	562
5	Akkerweb eradicative	Proxanil	2	2.67				
6	Weekly	Ranman Top	0.25	13	0.3			
6	Curative treatment with Cymbal 45 in high-risk periods	Cymbal 45	0.25	3.67		24	7	-63
7	Weekly	Ranman Top	0.5	9.67				
7	Treatment 2 times in high-risk periods	Zorvec Enicade	0.15	2	0.4	29	7	**
7	Treatment 2 times in high-risk periods	Curzate M68 WG	1.5	2				
8	Weekly	Ranman Top	0.25	9.67				
8	Treatment 2 times in high-risk periods	Zorvec Enicade	0.15	2	0.2	23	7	**
8	Treatment 2 times in high-risk periods	Curzate M68 WG	1.5	2				
LSD						NS	NS	NS

* depending on disease pressure

** no information about product price

(Oversigt over Landsforsøgene 2018).

Treatment 2 (Table 1) was Ranman Top (0.5 l/ha), treatment 3 was Ranman Top 0.25 l/ha, treatment 4 was the Danish decision support system “Skimmelstyring” model A in which the dose of Ranman Top varied between 0.25 l/ha and 0.5 l/ha depending on late blight infection pressure (Figure 9). Treatment 5 was the Akkerweb model in which Ranman Top was used and varied between 0.25 l/ha and 0.5 l/ha and was supplemented with Proxanil (2.0 l/ha) and Cymbal 45 (0.25 kg/ha). In treatment 6, Ranman Top was used as in treatment 3 (0.25 l/ha) and supplemented with Cymbal 45 0.25 kg/ha in periods with increased infection pressure (start on 13 August). In treatment 7 Ranman Top was used as in treatment 2 (0.5 l/ha), and at first increase in infection pressure (13 August) Zorvec Enicade (0.15 l/ha) + Curzate M68 WG (1.5 kg/ha) was used two times at 10-day intervals. Treatment 8 was the same as treatment 7 but the use of Ranman Top during the season was as for treatment 3 (0.25 l/ha).

The development in attack of late blight came relatively late in the trial, and the disease development in untreated was only moderate in September. Spraying with the different treatments (3-8) had a very high impact on late blight (>96% control, Table 1) with no significant differences between the treatments.

Yields in untreated plots for the three trials were 586 hkg/ha and 110 hkg starch/ha (Table 1). Spraying in the different treatments gave a yield increase of 3% to 8% tubers and 6% to 11% starch with no significant differences between the treatments in gross or net yield.

The treatment that was recommended in both decision support systems could have been reduced in the first half of the season without risk of infections (no risk of infection and no spores in the air, Figure 9). The Akkerweb model often recommended fungicide treatments just after irrigation even if no infection could be initiated under these conditions.

Photo 6. Harvesting trials, Flakkebjerg 2018. (Photo: Uffe Pilegård Larsen).

Curative control of late blight under field conditions

In order to test the effect of curative products on established lesions of late blight, a trial was set up in almost the same way as in 2014-2017. However, in 2018 the experiment was carried out in three different starch varieties, Kuras, Eurogrande and Wotan. Spraying with Ranman Top, Proxanil and Cymbal 45 was done in three steps as explained in Table 2.

Table 2. Trial plan for testing effect of curative control on established lesions of late blight under field conditions. Dose of Ranman Top is indicated for the different treatments, 0.06 l/ha (0.06), 0.25 l/ha (0.25) or 0.5 l/ha (0.5). Proxanil (PROX) and Cymbal 45 (CYM) are used as curative sprayings at different times in the epidemic, see text for explanations. Varieties Kuras, Eurogrande and Wotan, Flakkebjerg, 2018.

	22-06	29-06	05-07	20-07	25-07	01-08	08-08	13-08	21-08	29-08	05-09	10-09	14-09	17-09	20-09	25-09
1																
2									0.5	0.5	0.5	0.5		0.5	0.5	
3									2.5PROX	0.25CYM	0.5	0.5		0.5	0.5	
4								2.0PROX	0.5	0.5	0.5	0.5		0.5	0.5	
5	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06					
6	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.5		0.5	0.5	
7	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	2.5PROX	0.25CYM	0.5	0.5	
8	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	2.0PROX	0.5		0.5	0.5	
9	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25		0.25		
10	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25		0.25	0.5	
11	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25		0.25	2.5PROX	0.25CYM
12	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25		2.0PROX	0.5	

2.5PROX Proxanil 2.5 l/ha + Ranman Top 0.25 l/ha   0.25CYM Cymbal 45 0.25 kg/ha + Ranman Top 0.25 l/ha

2.0PROX Proxanil 2.0 l/ha + Ranman Top 0.5 l/ha

The sprayings were divided into three steps (A: treatments 2-4, B: treatments 5-8 and C: treatments 9-12) in the three varieties as shown in Table 2. Treatment 1 was untreated for the whole season. Results are shown in Figures 11-12 and Table 3. Spraying in the three steps was:

A: In treatments 2-4, the plots were untreated until the first increase in infection pressure and first small symptoms were seen on 20 August (Figures 1 and 11; Tables 2-3). Spraying was done on 21 August at a disease level of 0.01% (Kuras), 0.06% (Eurogrande) and 0.2% (Wotan) (Table 3). In treatment 2 Ranman Top (0.5 l/ha) was sprayed on 21 August and then at weekly intervals for the rest of the season (contact fungicide). In treatment 3, Proxanil + Ranman Top (2.5 l/ha + 0.25 l/ha) was sprayed on 21 August followed by Cymbal 45 + Ranman Top (0.25 kg/ha + 0.25 l/ha) on 29 August and then Ranman Top (0.5 l/ha) during the rest of the season. In treatment 4 spraying with Proxanil + Ranman Top (2.0 l/ha + 0.5 l/ha) was done one week before symptoms were seen, on 13 August (no attacks of late blight). For the rest of the season spraying was done with Ranman Top (0.5 l/ha).

B: In treatments 5-8 all plots were sprayed with Ranman Top (0.06 l/ha) to allow late blight to attack later in the season. Treatment 5 was untreated from 5 September. On 10 September when the infection pressure was increasing again (Figure 1), treatment 6 was sprayed with Ranman Top (0.5 l/ha) and at weekly intervals for the rest of the season. In treatment 7, Proxanil + Ranman Top (2.5 l/ha + 0.25 l/ha) was sprayed on 10 September followed by Cymbal 45 + Ranman Top (0.25 kg/ha + 0.25 l/ha) on 14 September and then Ranman Top (0.5 l/ha) for the rest of the season (approx. 3% attack in Kuras, 1.9-2.7% in Eurogrande and 5%-6% in Wotan on 10 September, Table 3). In treatment 8 spraying with Proxanil + Ranman Top (2.0 l/ha + 0.5 l/ha) was done one week before, on 5 September (approx. 0.4% attack of late blight in Kuras, 0.7% in Eurogrande and 0.2% in Wotan, Table 3). For the rest of the season spraying was done with Ranman Top (0.5 l/ha).

C: In treatments 9-12, all plots were sprayed with Ranman Top (0.25 l/ha) to allow late blight to attack late in the season. On 20 September, treatment 10 was sprayed with Ranman Top (0.5 l/ha). In treatment 11, Proxanil + Ranman Top (2.5 l/ha + 0.25 l/ha) was sprayed on 20 September followed by Cymbal 45 + Ranman Top (0.25 kg/ha + 0.25 l/ha) on 25 September (approx. 3-5% attack of late blight in Kuras and Eurogrande and 12% in Wotan on 20 September, Table 3). In treatment 12, spraying with Proxanil + Ranman Top (2.0 l/ha + 0.5 l/ha) was done three days before, on 17 September, and then Ranman Top (0.5 l/ha) on 21 September (approx. 2% attack of late blight in Kuras and Eurogrande and 12% attack in Wotan, Table 3)

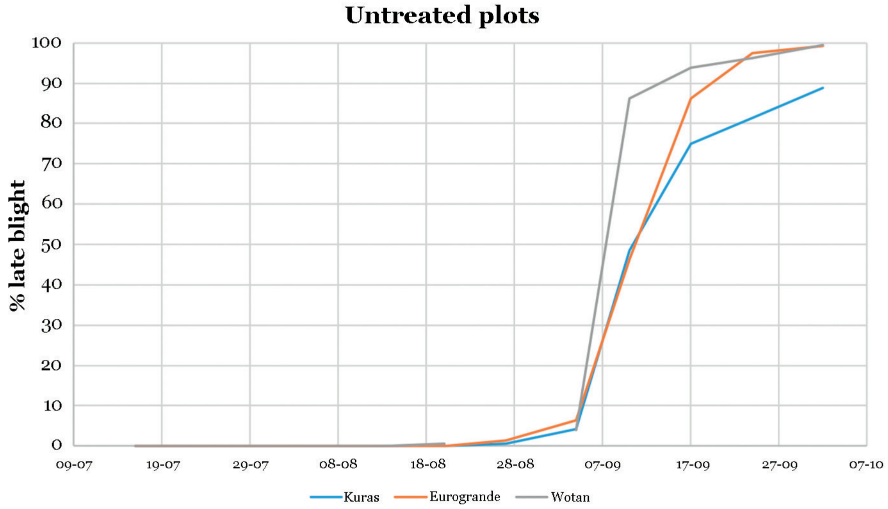

Figure 11. Development of late blight in untreated plots of the three varieties Kuras, Eurogrande and Wotan in the trial. Flakkebjerg 2018.

At the end of the season, on 2 October (Figure 11) the attack of late blight in untreated was 89% (Kuras), 99% (Eurogrande) and 100% (Wotan). The best effects of the curative sprayings were at the sprayings 13 and 21 August. The effects of the different sprayings (Figure 12; Tables 2-3) were for the three varieties:

Kuras:
Step A: In treatment 2 (Ranman Top 0.5 l/ha from 21 August) the attack at the end of the season, 24 September, was in Kuras reduced from 81% to 26% (76% disease control based on the area under the disease pressure curve (AUDPC), Figure 12 and Table 3). But in treatment 3 the attack on 24 September was kept at a lower level, 9.3% attack. The best effect was obtained in treatment 4 in which the level of attack was 2.8%. The best curative effect was clearly obtained when spraying Proxanil + Ranman Top (2.0 l/ha + 0.5 l/ha) on 13 August, one week before symptoms were seen (95% control based on AUDPC). Spraying (treatment 3) with Proxanil + Ranman Top (2.5 l/ha + 0.25 l/ha) on 21 August (the very first symptoms, disease level 0.01%) followed by Cymbal 45 + Ranman Top (0.25 kg/ha + 0.25 l/ha) also had a good effect but slight less disease control (87% disease control). There were 8 days between the sprayings with Proxanil and Cymbal 45 in treatment 3 (Figure 12; Table 3).

In Step B in which low doses were applied until 5 and 10 September, spraying in general reduced the disease development to moderate attacks in September (Figure 12; Table 3). Spraying was done at a disease level of 3% in treatments 6-7. No effect of the curative spraying in treatment 7 *relative to* treatments 5 or 6 could be seen (72-74% disease control). The spraying in treatment 8 one week earlier at approximately 0.4% late blight reduced the disease development (9.5% attack on 24 September). The curative effect when spraying in early September was clearly lower than when spraying in August at the start of the epidemic. But there was still an effect from spraying with Proxanil + Ranman Top (2.0 l/ha + 0.5 l/ha) curatively (89% disease control). There were 4 days between the sprayings with Proxanil and Cymbal 45 in treatment 7.

In step C, Ranman Top was sprayed with 0.25 l/ha until 10 September. In these treatments, there was only a weak disease development (due to season-long spraying with Ranman Top 0.5 l/ha), and at the end of September the level of attack of late blight was low. At this late stage, no differences between treatment 9 and treatments 10-11 could be seen. No effect of the curative sprayings (*relative* to preventive spraying in treatment 10) could be seen at the end of the season (Figure 12; Table 3). There were 5 days between the sprayings with Proxanil and Cymbal 45 in treatment 11.

Eurogrande:
Step A: In treatment 2, the attack on 24 September in variety Eurogrande was reduced to 11.5% (87% disease control) but in treatments 2 and 3 the attack at the end of the season was kept at a lower level, 5.5-5.8% attack. Based on disease development during the whole season, a slightly better effect was seen in treatment 4 (95% disease control) *relative to* treatment 3 (92% disease control) because of a lower level of attack on 2 October in treatment 4 (Figure 12; Table 3). There were 8 days between the sprayings with Proxanil and Cymbal 45 in treatment 3.

In Step B in which low doses were applied until 5 and 10 September, spraying in general reduced the disease development to moderate attacks in September. Spraying was done at a disease level in treatments 6-7 of 1.9-2.7%. No effect of the curative sprayings in treatment 7 *relative* to treatment 6 could be seen (79-82% disease control). The spraying in treatment 8 one week earlier at approximately 0.7% late blight only reduced the disease development very slightly (17.8% attack on 24 September; 83% disease control). In this variety, the curative effect when spraying in early September was clearly lower than in August at the start of the epidemic (Figure 12).

In step C, Ranman Top was sprayed with 0.25 l/ha until 10 September. In these treatments, there was only a weak disease development (due to season-long spraying with Ranman Top 0.5 l/ha), and at the end of September the level of attack of late blight was low in Eurogrande. At this late stage only a slightly better disease control was seen in treatments 11 and 12 with no differences between treatments 11 and 12 (Figure 12; Table 3). There were 5 days between the sprayings with Proxanil and Cymbal 45 in treatment 11.

Table 3. Attack of late blight in the different treatments in Kuras (top), Eurogrande (centre) and Wotan (bottom). Area under disease pressure curve (AUDPC) and relative values for AUDP for each set (set A treatment 1 =100, set B treatment 5 =100 and set C treatment 9 = 100). The trial plan is shown in Table 2. Flakkebjerg, 2018.

Variety: Kuras

	06/08	13/08	20/08	27/08	04/09	10/09	17/09	24/09	02/10	AUDPC	% control	*Relative within the set*		
1	0.0	0.0	0.01	0.55	4.2	48.5	75,0	81.3	88.8	1838.3	0	100		
2	0.0	0.0	0.00	0.25	2.2	3.1	8.8	26.0	38.8	448.7	76	24		
3	0.0	0.0	0.01	0.15	0.6	1.0	2.8	9.3	32.8	231.0	87	13		
4	0.0	0.0	0.00	0.01	0.2	0.5	0.9	2.8	14.3	88.6	95	5		
5	0.0	0.0	0.00	0.08	0.4	2.8	12.0	25.0	48.8	487.6	73		100	
6	0.0	0.0	0.00	0.08	0.5	3.0	13.3	22.0	55.0	501.4	73		103	
7	0.0	0.0	0.00	0.04	0.3	3.0	10.8	27.3	53.8	516.2	72		106	
8	0.0	0.0	0.00	0.01	0.4	0.9	4.3	9.5	24.3	206.4	89		42	
9	0.0	0.0	0.00	0.01	0.3	0.6	1.8	6.0	23.5	157.0	91			100
10	0.0	0.0	0.00	0.03	0.2	0.7	2.3	7.8	26,0	184.4	90			117
11	0.0	0.0	0.00	0.01	0.3	1.0	2.0	5.5	28.0	175.2	90			112
12	0.0	0.0	0.00	0.02	0.2	0.8	2.0	4.5	21.8	141.0	92			90

Variety: Eurogrande

	06/08	13/08	20/08	27/08	04/09	10/09	17/09	24/09	02/10	AUDPC	% control	*Relative within the set*		
1	0.0	0.0	0.02	1.33	6.4	46.3	86.3	97.5	99.3	2087.3	0	100		
2	0.0	0.0	0.06	0.87	1.9	2.9	3.9	11.5	28.7	267.1	87	13		
3	0.0	0.0	0.02	1.16	2.0	2.2	2.3	5.5	20.0	173.9	92	8		
4	0.0	0.0	0.00	0.11	0.2	0.5	1.1	5.8	13.5	109.8	95	5		
5	0.0	0.0	0.00	0.04	0.3	1.7	12.8	25.0	61.3	535.4	74		100	
6	0.0	0.0	0.00	0.11	0.9	1.9	10.8	20.5	45.5	429.9	79		80	
7	0.0	0.0	0.00	0.09	0.4	2.7	13.0	17.8	31.8	371.8	82		69	
8	0.0	0.0	0.01	0.31	0.7	2.4	8.0	17.8	38.3	364.6	83		68	
9	0,0	0.0	0.00	0.03	0.1	0.6	1.6	6.5	18.8	139.8	93			100
10	0.0	0.0	0.00	0.02	0.2	0.7	2.8	10.0	27.5	210.2	90			150
11	0.0	0.0	0.00	0.02	0.2	0.5	1.7	4.8	14.3	108.9	95			78
12	0.0	0.0	0.00	0.02	0.2	0.5	1.4	5.0	17.0	119.6	94			86

Variety: Wotan

	07/08	14/08	23/08		06/09	12/09	19/09	26/09	02/10	AUDPC	% control	*Relative within the set*		
1	0.0	0.0	0.48		4.0	86.3	93.8	96.3	99.5	2186.5	0	100		
2	0.0	0.0	0.23		1.2	3.3	19.3	32.0	49.5	526.9	76	24		
3	0.0	0.0	0.15		0.1	1.7	6.5	12.5	19.5	198.7	91	9		
4	0.0	0.0	0.06		0.2	2.2	8.3	15.5	31.0	268.5	88	12		
5	0.0	0.0	0.03		0.3	4.5	17.5	32.5	55.0	531.6	76		100	
6	0.0	0.0	0.07		0.3	5.3	19.0	33.3	43.0	516.1	76		97	
7	0.0	0.0	0.14		0.4	6.0	22.5	37.8	50.5	598.7	73		113	
8	0.0	0.0	0.08		0.2	1.4	4.0	9.5	18.8	157.9	93		30	
9	0.0	0.0	0.02		0.3	2.3	11.5	22.3	31.5	337.5	85			100
10	0.0	0.0	0.05		0.3	2.5	18.0	27.8	39.8	445.4	80			132
11	0.0	0.0	0.03		0.2	2.8	9.0	16.0	27,0	268.4	88			80
12	0.0	0.0	0.05		0.2	3.0	12.3	21.8	30.8	341.2	84			101

Wotan:
Step A: In treatment 2 the attack on 26 September was reduced to 32% (76% disease control) in variety Wotan but in treatments 2 and 3 the attack at the end of the season was kept at a lower level, 12.5-15.5% attack, with no difference in disease control (88-91% control, Figure 12; Table 3). There were 8 days between the sprayings with Proxanil and Cymbal 45 in treatment 3.

In Step B in which low doses were applied until 5 and 10 September, spraying in general reduced the disease development to moderate attacks in September. Spraying was done at a disease level in treatments 6-7 of 5-6% in Wotan (Table 3). At this disease level, no effect of the curative sprayings in treatment 7 *relative* to treatments 5 and 6 could be seen (73-76% disease control). The spraying in treatment 8 one week earlier at approximately 0.2% late blight reduced the disease development (9.5% attack on 26 September) and gave 93% disease control (Figure 12; Table 3).

In step C, Ranman Top was sprayed with 0.25 l/ha until 10 September. In these treatments, there was only a slight disease development (due to season-long spraying with Ranman Top 0.5 l/ha), and at the end of September the level of attack of late blight was low in Wotan also. At this late stage there were no differences in disease control of treatments 9–12. There were 5 days between the sprayings with Proxanil and Cymbal 45 in treatment 11 (Figure 12; Table 3).

Conclusions: Spraying with Proxanil + Ranman Top (2.0 l/ha + 0.5 l/ha) at a very low infection pressure and at no observed late blight (step A, treatment 4, Figure 3), had a high impact on the development of late blight during the rest of the season. Spraying one week later (treatment 3) with Proxanil + Ranman Top (2.5 l/ha + 0.25 l/ha) at a disease level of 0.01-0.2% (all three varieties) followed after one week by Cymbal 45 + Ranman Top (0.25 kg/ha + 0.25 l/ha) had slightly less effect in Kuras or the same effect in Eurogrande and Wotan, but still gave good season-long control. In comparison, spraying only preventively with Ranman Top (0.5 l/ha, treatment 2) gave a moderate disease control (when starting at low disease pressure).

The curative effect when spraying in early September (step B) was clearly lower than in August at the start of the epidemic. There was only effect of spraying curatively (treatment 8) with Proxanil + Ranman Top in varieties Kuras and Wotan (Table 3). No effect (step C) of the curative sprayings could be seen at the end of the season.

In accordance with the protocol the trial was not harvested.

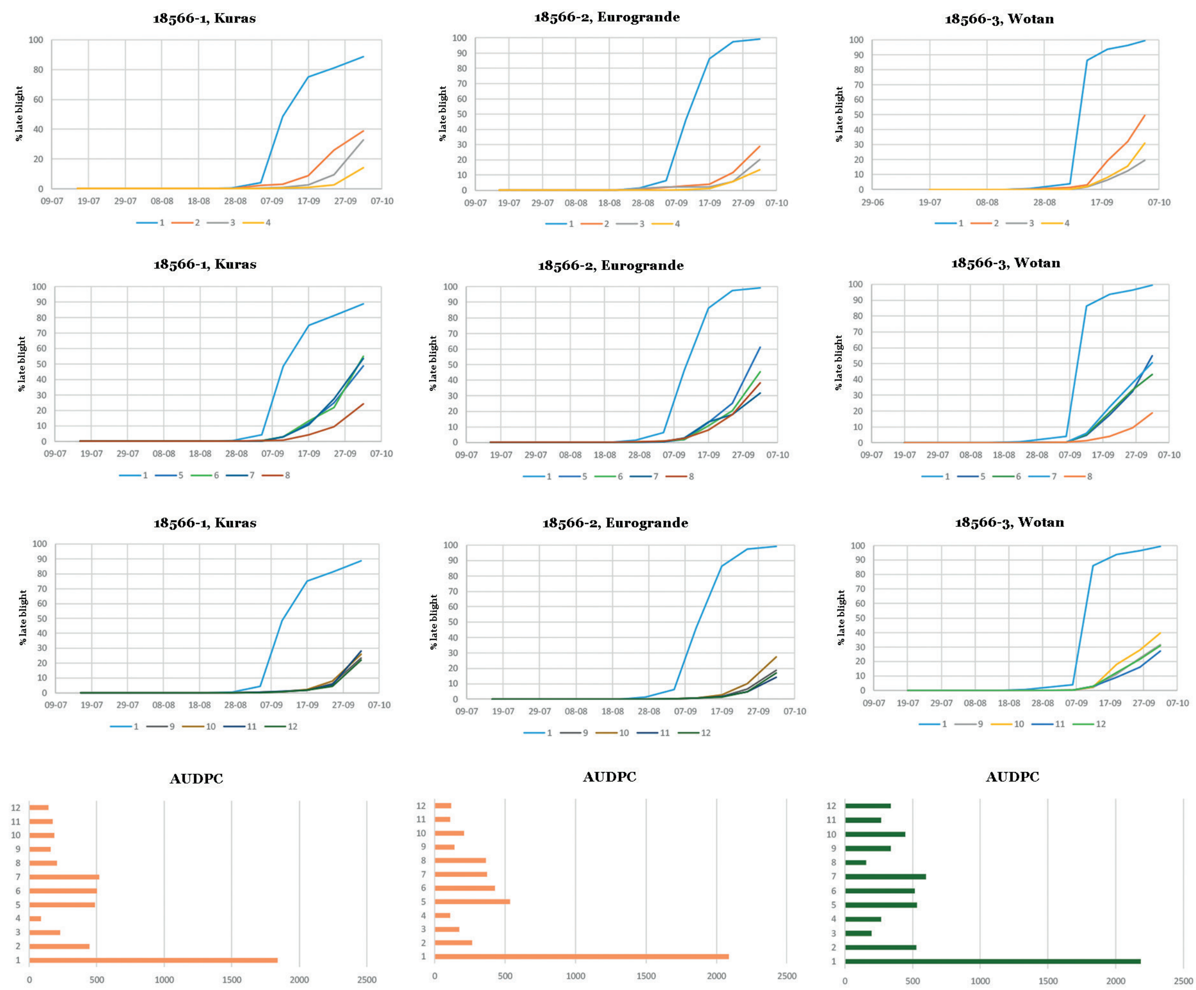

Figure 12. Development of late blight in field trials with at the top, step A, early curative sprayings in treatments 1-4; centre, step B, curative sprayings in treatments 5-8 and bottom, step C, late curative treatments 9-12. Development is shown for three different varieties, Kuras (left column), Eurogrande (centre column) and Wotan (right column). Values for area under the disease pressure curve (AUDPC) are shown for each variety. Treatment numbers are explained in Table 2. Flakkebjerg, 2018.

Control of early blight (*Alternaria solani*)

Field trials with control of early blight were carried out in 2018 in cooperation with SEGES at three locations (Flakkebjerg, Arnborg and Billund). The trial was performed in the variety Kuras in order to evaluate the effect of spraying with different strategies as explained in Table 4. Sprayings were at 14-day intervals. All strategies were started at the same time at the first small symptoms (4-9 July, Table 4). The objective of the trial was to see the effect of the products on early blight, and a cover spray was performed with Revus Top (0.6 l/ha) against late blight (*P. infestans*). Plots sprayed with Revus Top or Vendetta were not cover sprayed. Only low levels of attack of late blight were observed in the trial.

The trial at Flakkebjerg was artificially inoculated on 15 June 2018 with autoclaved barley seeds inoculated with *A. solani* and *A. alternata* (seeds were placed in the furrow between the plants). The isolates were a mixture of *A. solani* + *A. alternata* (4:1). Six isolates of *A. solani* collected from Jutland in 2016 and 2017 were used, all of the type F129L (axoxystrobin resistant).

Photo 7. Severe infections of early blight (*Alternaria solani*), Flakkebjerg, at the end of August 2018. (Photo: Hans Hansen).

The first attacks on the lower leaves were detected on 13 July. However, the weather conditions were not favourable for disease development in July with hot and dry weather. It was not until 11-12 August when the first rain came and again from the end of August that conditions for development of early blight improved. In the last part of August and in September there was a severe development with 94% attack on 1 October (Figure 13).

At the last assessments on 25 September and 1 October there was also influence from general desiccation, and certain reservations must be made concerning the assessment. Due to the relatively late start of the disease development, there was an uneven start and spread of the attacks with variation between the plots.

An assessment of early blight at Flakkebjerg on 11 September (20 days after spray E) and 25 September (34 days after spray E) gave an estimate of short and long-term efficacy while the final AUDPC value gave an estimate of the overall efficacy (Table 5). A good effect against early blight 20 days after spray E was obtained with treatments 8-10: 97-100% control, treatments 3-7: 93-95% control and treatment 2: 89% control (for the treatment details, see Table 4). At the assessment on 25 September (34 days after spray E) the effects were still high for treatments 8-9: 98% control but had declined for treatments 6-7 and 10 to 78-86% control and for treatments 3-5 to 65-73% control. For treatment 2 the effect had declined to 52% control. Overall, based on the AUDPC values the level of effect against early blight was for treatments 8-9: 99% control, for treatments 6-7 and 10: 85-90% control, for treatments 3-5: 76-81% control and for treatment 2: 70% control (Figure 14; Table 5).

Table 4. Trial plan for testing different control strategies against early blight (*Alternaria solani*). Actual dates for the sprayings are shown in the table. Variety Kuras. Flakkebjerg, Arnborg and Billund 2018.

Flakkebjerg	A 09-July	B 31-July	C 9-Aug	D 22-Aug	E 29-Aug
1					
2	0.6 RT	0.6 RT	0.5 A	0.25 S	
3	0.6 RT	0.6 RT	0.5 VEN	0.25 S	
4	0.6 RT	0.6 RT	0.25 S	0.25 S	
5	0.6 RT	0.25 S	0.6 RT	0.25 S	
6	0.4 NA	0.4 NA	0.25 S	0.4 NA	0.25 S
7	0.4 NA	0.4 NA	0.25 S	0.25 S	
8	0.4 NA	0.4 NA	0.45 P	0.45 P	
9	0.4 NA	0.45 P	0.4 NA	0.45 P	
10	0.25 S	0.25 S	0.25 S	0.25 S	

Arnborg	A 5-Jul	B 19-Jul	C 30-Jul	D 16-Aug	E 28-Aug
1					
2	0.6 RT	0.6 RT	0.5 A	0.25 S	
3	0.6 RT	0.6 RT	0.5 VEN	0.25 S	
4	0.6 RT	0.6 RT	0.25 S	0.25 S	
5	0.6 RT	0.25 S	0.6 RT	0.25 S	
6	0.4 NA	0.4 NA	0.25 S	0.4 NA	0.25 S
7	0.4 NA	0.4 NA	0.25 S	0.25 S	
8	0.4 NA	0.4 NA	0.45 P	0.45 P	
9	0.4 NA	0.45 P	0.4 NA	0.45 P	
10	0.25 S	0.25 S	0.25 S	0.25 S	

Billund	A 4-Jul	B 18-Jul	C 1-Aug	D 15-Aug	E 29-Aug
1					
2	0.6 RT	0.6 RT	0.5 A	0.25 S	
3	0.6 RT	0.6 RT	0.5 VEN	0.25 S	
4	0.6 RT	0.6 RT	0.25 S	0.25 S	
5	0.6 RT	0.25 S	0.6 RT	0.25 S	
6	0.4 NA	0.4 NA	0.25 S	0.4 NA	0.25 S
7	0.4 NA	0.4 NA	0.25 S	0.25 S	
8	0.4 NA	0.4 NA	0.45 P	0.45 P	
9	0.4 NA	0.45 P	0.4 NA	0.45 P	
10	0.25 S	0.25 S	0.25 S	0.25 S	

0.5 A	Amistar 0.5 l/ha
0.6 RT	Revus Top 0.6 l/ha
0.5 VEN	Vendetta (azoxystrobin + fluazinam) 0.5 l/ha
0.4 NA	Narita 0.4 l/ha + "Additiv til Ranman" 0.1 l/ha
0.45 P	Propulse 0.45 l/ha
0.25 S	Signum WG 0.25 kg/ha

Table 5. Attack of early blight (*Alternaria solani*) at Flakkebjerg 20 and 34 days after spraying D (22 August), AUDPC and yield. Treatments are shown in Table 4. Variety Kuras. Flakkebjerg, 2018.

	% *Alternaria* 20 days after spray D		% *Alternaria* 34 days after spray D							
	11-sep	% ctrl	25-sep	% ctrl	AUDPC	% ctrl	Hkg/ha	Rel.	Hkg starch	Rel.
1	81.25	*0*	92.5	*0*	2611.2	*0*	676.7	*100*	100.1	*100*
2	8.75	*89*	44.5	*52*	779.3	*70*	729.2	*108*	113.5	*113*
3	5.50	*93*	31.3	*66*	569.9	*78*	725.1	*107*	115.0	*115*
4	6.00	*93*	32.5	*65*	633.9	*76*	733.8	*108*	110.3	*110*
5	5.00	*94*	25.0	*73*	491.4	*81*	736.8	*109*	106.2	*106*
6	4.00	*95*	16.5	*82*	350.8	*87*	723.5	*107*	118.1	*118*
7	4.50	*94*	20.3	*78*	404.4	*85*	717.1	*106*	109.0	*109*
8	0.188	*100*	1.4	*98*	30.1	*99*	757.3	*112*	116.3	*116*
9	0.173	*100*	1.5	*98*	30.6	*99*	796.7	*118*	128.6	*128*
10	2.25	*97*	13.0	*86*	264.2	*90*	751.3	*111*	119.6	*119*

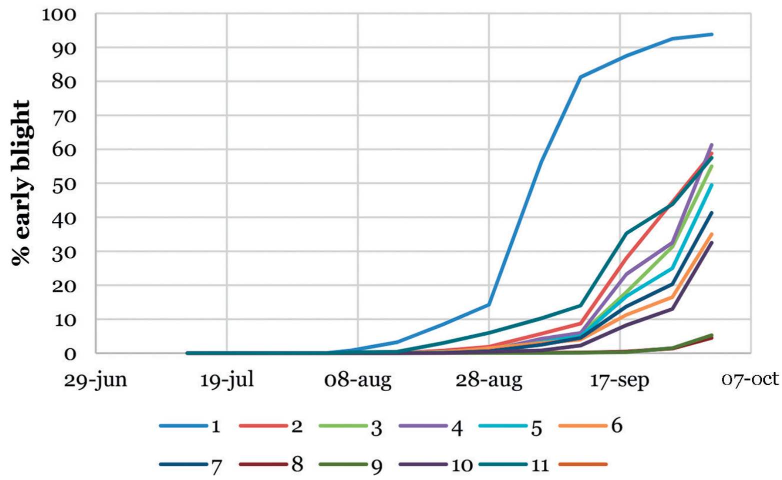

Figure 13. % attack of early blight (*Alternaria solani*) and the development of the disease in plots with different spray strategies. Inoculation on 15 June with isolates collected in Jutland (F129L type). The different treatment numbers are explained in Table 4. Variety Kuras, Flakkebjerg 2018.

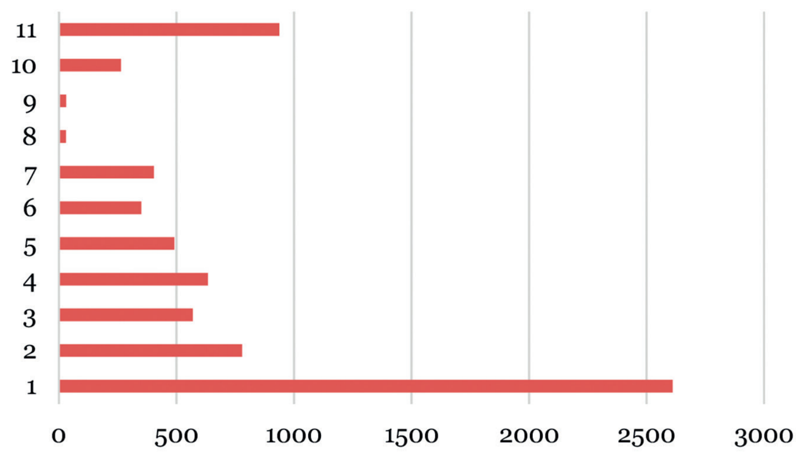

Figure 14. Area under disease pressure curve in the trial at Flakkebjerg. Treatment numbers are explained in Table 4. Variety Kuras, Flakkebjerg, 2018.

The attacks of early blight at Arnborg and Billund were also severe in 2018. First symptoms were seen on 26 July at Arnborg and 7 August at Billund with rapid disease development in late August and in September. At the end of the season the attack was 94% at Arnborg and 75% at Billund (Figures 5-6). The assessment of early blight at the end of the season was difficult in 2018 due to early senescing of the potato crop with yellow and brown leaves. To be sure that the assessment is only attack of early blight, the assessments from 28 August have been collected in Table 6. Attack in untreated plots was 14% at Flakkebjerg, 15% at Arnborg and 22% at Billund. At Arnborg, treatments 3-10 had a good effect against early blight with treatments 8-9 as the best (the same as Flakkebjerg). At Billund, treatments 3-9 had some effect with treatment 8 as the best. In all trials, the lowest level of effect was seen after treatment 2. However, at Billund also treatment 10 (Signum) had a poor effect (Table 6).

Attacks at the end of the season for the two trials in Jutland with natural infections (Arnborg and Billund) and the trial at Flakkebjerg with artificial inoculations are shown in Table 7.

Table 6. Attack of early blight (*Alternaria solani*), 28 August 2018 in the different treatments of the trials. Actual dates and products used are shown in Table 4. Variety Kuras. Flakkebjerg, Arnborg and Billund 2018.

	A	B	C	D	E	% attack of *Alternaria*, 28 August		
						Flakkebj.	Arnborg	Billund
1						14.3	15	22
2	0.6 RT	0.6 RT	0.5 A	0.25 S		1.9	2	12
3	0.6 RT	0.6 RT	0.5 VEN	0.25 S		1.1	0.5	8
4	0.6 RT	0.6 RT	0.25 S	0.25 S		0.8	1	7
5	0.6 RT	0.25 S	0.6 RT	0.25 S		0.7	0.9	7
6	0.4 NA	0.4 NA	0.25 S	0.4 NA	0.25 S	1.5	0.5	8
7	0.4 NA	0.4 NA	0.25 S	0.25 S		0.6	1	8
8	0.4 NA	0.4 NA	0.45 P	0.45 P		0.1	0.2	3
9	0.4 NA	0.45 P	0.4 NA	0.45 P		0.04	0.1	8
10	0.25 S	0.25 S	0.25 S	0.25 S		0.5	0.8	11

A: Amistar 0.5 l/ha, NA: Narita 0.4 l/ha, RT: Revus Top 0.6 l/ha, P: Propulse 0.45 l/ha, S: Signum WG 0.25 kg/ha and VEN: Vendetta 0.5 l/ha. Narita was in all sprayings mixed with an adjuvant (0.1 l/ha "Additiv til Ranman").

The yield in untreated plots at Flakkebjerg was 676.7 hkg tubers/ha and 100.1 hkg starch/ha (Table 7). The yield increase was in general 6-18% for tubers and 6-29% for starch. The highest yield was obtained for treatment 9 (18% tubers and 29% starch) followed by treatments 8 and 10 (11-12% tubers, 16-20% starch) and treatments 2-7 (6-9% tubers, 6-15% starch).

The yield in untreated plots at Arnborg and Billund was 516 hkg tubers/ha and 99 hkg starch/ha (Table 7). The yield increase was in general 4-9% for tubers and 7-13% for starch. The highest yield was obtained for treatments 4, 7, 8 and 10 (8-9% tubers and 12-13% starch).

The net yield after spraying against early blight was approximately DKK 3,800 to 4,000 in treatments 8-10 in all the three trials in 2018 (13-14% increase in net yield, Table 7) and approximately DKK 2,900 to 3,000 in treatments 3-7 (10% increase, Table 7).

The differences between the products are not statistically significant.

Table 7. Attack of early blight (*Alternaria solani*), yield and yield increase for all three trials, the trial at Flakkebjerg (artificial inoculation) and the trials at Arnborg and Billund (natural infections). Treatments are shown in Table 4. Net yield (DKK) is calculated by subtracting the cost of fungicides and sprayings. Variety Kuras. Flakkebjerg, Arnborg and Billund, 2018.

Treatment	% *Alternaria*		Treatment cost/ha	Yield and yield increase		
				Hkg tubers/ha	Hkg starch/ha	Net yield DKK/ha
3 trials	*10 Sept.*	*18 Sept.*				
1.	64.6	87.5	2,645	**570**	**100**	**29,262**
2.	30.7	57.9	3,263	16	5	1,123
3.	21.5	47.1	3,195	35	11	2,868
4.	21.7	50.4	3,265	47	11	3,042
5.	21.8	51.9	3,203	33	10	2,729
6.	18.0	37.5	3,309	29	11	2,793
7.	20.3	48.8	3,201	42	11	2,894
8.	9.1	18.6	3,259	56	14	3,786
9.	16.3	27.2	3,259	53	14	3,998
10.	22.7	51.3	3,277	56	14	3,992
LSD				*NS*	*NS*	
Flakkebjerg	*25 Sept.*	*1 Oct.*				
1.	92.5	93.8	1,536	**677**	**100**	**30,509**
2.	44.5	58.8	2,495	53	13	3,326
3.	31.3	55.0	2,427	48	15	3,871
4.	32.5	61.3	2,497	57	10	2,294
5.	25.0	49.5	2,311	60	18	4,909
6.	16.5	35.0	2,293	47	18	4,991
7.	20.3	41.3	2,185	40	9	2,190
8.	1.4	4.5	2,243	81	16	4,471
9.	1.5	5.3	2,243	120	28	8,410
10.	13.0	32.5	2,261	75	19	5,499
LSD				*38*	*11*	
Arnborg and Billund	*3 Sept.*	*11 Sept.*				
1.	50.6	84.4	3,200	**516**	**99**	**28,637**
2.	23.8	57.5	3,647	-2	1	23
3.	16.6	43.1	3,579	28	9	2,367
4.	16.3	45.0	3,649	42	12	3,417
5.	20.3	53.1	3,649	19	7	1,641
6.	18.8	38.8	3,817	20	7	1,697
7.	20.3	52.5	3,709	42	12	3,252
8.	13.0	25.6	3,767	43	13	3,443
9.	23.8	38.1	3,767	20	7	1,795
10.	27.5	60.6	3,785	47	12	3,242
LSD				*NS*	*NS*	

NS = not significant
(Oversigt over Landsforsøgene 2018).

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VI Influence of adjuvants on the activity of glyphosate products

Solvejg K. Mathiassen

When glyphosate is applied under challenging conditions, a tank mix with ammonium sulphate is recommended. Another adjuvant recommended for glyphosate is NovaBalance that specifically should reduce the negative effects of hard water. The latest glyphosate products are claimed to contain a surfactant composition maximising leaf uptake. Faster leaf uptake means shorter cultivation intervals and higher reliability under challenging conditions. Consequently, the benefit of applying the new glyphosate products in a tank mix with adjuvants is expected to be lower. In this study we compared the activity of three generations of glyphosate products: (1) acting alone, (2) mixed with ammonium-sulphate + a non-ionic surfactant and (3) mixed with NovaBalance + a non-ionic surfactant. All three glyphosate products showed significantly higher activity in the tank mix with ammonium-sulphate compared to using either no adjuvant or NovaBalance. These results illustrate that the new glyphosate products Roundup Flex and Roundup PowerMax can still benefit from being tank mixed with ammonium-sulphate + a surfactant.

Three glyphosate products commonly available to Danish farmers were examined. Firstly, Glypper (360 g/l glyphosate, previously known as Taifun 360 SL), which was authorised for use in Denmark in 2012. Secondly, Roundup Flex (480 g/L glyphosate), which belongs to the second generation of glyphosate products with a higher concentration of glyphosate and a shorter cultivation interval (6 hours for annuals, 2 days for couchgrass and 5 days for perennials). Finally, Roundup PowerMax (720 g/kg), which - being authorised in 2015 - is the most recent formulation of glyphosate on the Danish market. In contrast to the other two products Roundup PowerMax is a granular formulation. Cultivation intervals are similar to those of Roundup Flex, with an additional claim of less sensitivity to hard water.

We compared the efficacy of these three glyphosate products: (1) acting alone, (2) in a tank mix with 2 kg/ha ammonium-sulphate + 0.2% Contact (a non-ionic surfactant) and (3) with 0.2% NovaBalance + 0.2% Contact (Table 1). NovaBalance is a chelating, complex binding adjuvant which inactivates the cations and regulates the pH of the spray liquid. The experiment was carried out on two test weeds: rat's-tail fescue (*Vulpia myuros*) and black bindweed (*Polygonum convolvulus*).

The test weeds were grown outdoors in a potting mix consisting of sand, soil and peat, which included all necessary micro- and macronutrients. Rat's-tail fescue was sown in 1-L pots, and after germination the number of plants per pot was reduced to eight. The plants were sprayed at the 3-4 leaf stage on 3 August. The germination of black bindweed seeds is often low and uneven, and in order to generate uniform plants the seeds were sown in trays in the glasshouse and the seedlings were transplanted into 1-L pots (3 plants per pot) at the 1 leaf stage. The black bindweed was sprayed at the 3-4 leaf stage, on 4 July.

All spray solutions were prepared in tap water with a hardness of 17 °dH. Herbicide applications were carried out in a spray cabinet. Each treatment was applied at five doses in a spray volume of 150 L/ha. The doses ranged from 15 to 240 g/ha with three replicates per treatment. The plants were harvested three to five weeks after spraying. Fresh and dry weight were recorded.

A dose-response model was fitted to the data and the ED_{90} doses were estimated (Table 1).

Results and discussion

On both weed species the activity of the three glyphosate products was not significantly different three to five weeks after spraying when the herbicides were applied alone. The tank mix containing NovaBalance + Contact did not affect the activity of the three products. In contrast, the activity of all glyphosate products was significantly enhanced in the tank mix containing ammonium-sulphate + Contact. The ED_{90} doses of Glypper and Roundup Flex were reduced by 65-70% and those of Roundup PowerMax by 73-75% when tank mixed with ammonium-sulphate + Contact compared to the treatments with no adjuvant.

Several environmental factors are known to affect the activity of glyphosate. The uptake of glyphosate is reduced at low air humidity and in plants growing under dry soil conditions, while it is less affected by temperature. High concentrations of cations in the spray solutions inactivate glyphosate by complex binding (Kudsk and Mathiassen, 2007). At the time of spraying the water status of the test plants was good, the air temperature was high (16 to 22°C), the air humidity was medium (62 to 73%) and the herbicide solutions were prepared in water with a high content of cations (100 mg/L Ca, 12 mg/L Mg). In conclusion, water quality was the most challenging factor and therefore it was expected that Roundup PowerMax would perform better than Roundup Flex and Glypper when applied alone.

Table 1. Estimated ED_{90} doses of different glyphosate products when applied alone or in mixture with 2 kg/ha ammonium sulphate (AMS) + 0.2% Contact or 0.2% NovaBalance + 0.2% Contact. Figures in brackets are 95% confidence intervals.

Glyphosate product	Adjuvant	Rat's-tail fescue	Black bindweed
Glypper	None	249.5 (157.4-341.6)	202.7 (121.1-284.3)
	AMS + Contact	85.7 (56.2-115.1)	62.4 (37.2-87.5)
	NovaBalance + Contact	228.9 (160.3-297.6)	190.5 (146.4-234.6)
Roundup Flex	None	276.6 (179.3-373.8)	176.8 (129.2-224.3)
	AMS + Contact	89.4 (69.8-109.0)	61.0 (37.76-84.2)
	NovaBalance + Contact	250.5 (189.3-311.5)	184.4 (134.8-234.1)
Roundup PowerMax	None	224.3 (176.6-271.9)	209.0 (139.3-278.7)
	AMS + Contact	61.0 (44.8-77.1)	51.7 (27.6-75.8)
	NovaBalance + Contact	196.8 (153.4-240.2)	183.2 (94.6-271.8)

In a previous study we reported that NovaBalance and ammonium-sulphate increased the effects on couchgrass of Glyphogan, Glyfonova 480 and Roundup Flex, applied in carrier water with a high content of cations (Mathiassen, 2017). In contrast, NovaBalance was not able to inactivate the cations in the spray solutions in this study. These results illustrate that in spite of the improvement in formulation of glyphosate products over time, the new formulations still benefit from tank mixing with ammonium-sulphate + surfactant when applied under adverse application conditions – exemplified in this case by water with a high content of cations.

Black bindweed treated with Roundup PowerMax. From left to right: Untreated, 30, 60, 120 and 240 g/ha. From back to front row: No adjuvant, ammonium-sulphate + Contact and NovaBalance + Contact.

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VII Liquid nitrogen as an adjuvant to ALS-inhibitors

Solvejg K. Mathiassen

Previous studies reported a synergistic effect of adding the liquid fertiliser N32 to the spray solutions of both Broadway and Glyphomax. In 2018 we tested the effect of another liquid nitrogen fertiliser - Flex NS 24-4 – on the activity of three ALS inhibitors. We found that Flex NS 24-4 had quite variable effects, depending on both the herbicide and the weed species. On blackgrass, the effects of both Broadway and Atlantis OD were improved when applied in a tank mix with Flex NS 24-4. In contrast, for treating rat's-tail fescue both Broadway and Atlantis OD were unaffected by Flex NS 24-4. Antagonistic effects were seen on both rat's-tail fescue and annual meadow-grass when Cossack OD was mixed with Flex NS 24-4, with annual meadow-grass also showing a reduced effect when Atlantis OD was mixed Flex NS 24-4.

The effects of Broadway (68.3 g/kg pyroxsulam + 22.8 g/kg florasulam), Atlantis OD (10 g/L mesosulfuron + 2 g/L iodosulfuron + 30 g/L mefenpyr) and Cossack OD (7.5 g/L iodosulfuron + 7.5 g/L mesosulfuron + 2.5 g/L mefenpyr) alone and in mixture with Flex NS 24-4 were examined in a pot experiment using rat's-tail fescue (*Vulpia myuros),* blackgrass *(Alopecurus myosuroides)* and annual meadow-grass *(Poa annua)* as test plants. Flex NS 24-4 is a liquid fertiliser containing 23.7% nitrogen with 8.4% as N-ammonium, 5.1% as N-nitrate and 10.2% as N-amide plus 3.7% S.

Seeds of rat's-tail fescue, blackgrass and annual meadow-grass were sown in 1-L pots in a soil, sand and peat potting mixture. The pots were placed on outdoor tables. After emergence the number of seedlings per pot was reduced to the same number for each weed species.

All spray solutions were prepared in tap water with a hardness of 17 °dH. Herbicide applications were carried out in a spray cabinet on 3 July when the plants had 3 to 4 leaves and 1 to 2 tillers. Each treatment was applied at five different doses, in a spray volume of 179 L/ha, with 3 replicates per treatment. Broadway was applied in mixture with the recommended adjuvant PG26N (0.5 L/ha). Flex NS 24-4 was mixed in at 13 and 39 L/ha equal to 3.2 and 9.6 kg/ha N, respectively.

The plants were harvested 4 weeks after treatment. Fresh and dry weight were recorded. A dose-response model was fitted to the data and ED_{90} doses were estimated.

Results

The activity of Broadway on rat's-tail fescue was not affected by Flex NS 24-4 while the activity on blackgrass was significantly increased in the tank mix with 13 L/ha of N 24-4 (Table 1). Adding Flex NS 24-4 to Atlantis OD had no significant effect on rat's-tail fescue; however, the activity on blackgrass was significantly increased, while the activity on annual meadow-grass was reduced. The activity of Cossack OD was significantly reduced on rat's-tail fescue as well as on annual meadow-grass (Table 1). So generally, Flex NS 24-4 improved the herbicide activity on blackgrass, reduced the activity on annual meadow-grass and had no effect on rat's-tail fescue.

In previous studies we found that liquid nitrogen improved the efficacy of Broadway and Glyphomax (glyphosate) on rat's-tail fescue, and this effect was more pronounced at the 3-4 leaves stage compared to the tillering stage (Mathiassen, 2016). In the present study plants were sprayed at the early tillering stage, and the results did not support the previous findings indicating that the effect of liquid nitrogen may depend on interactions between weed species, growth stage, herbicide and environmental conditions.

Table 1. Influence of Flex NS 24-4 on the activity of Broadway + PG26N, Atlantis OD and Cossack OD when applied to rat's-tail fescue, blackgrass and annual meadow-grass. ED_{90} is the dose required for reducing fresh weight of the test plants by 90%. Brackets show 95% confidence intervals.

Herbicide	Adjuvant	ED_{90} (g/ha or L/ha)		
		Rat's-tail fescue	Blackgrass	Annual meadow-grass
Broadway	PG26N	39.7 (30.0-49.4)	3.68 (2.34-5.0)	
	PG26N + 13 L/ha NS 24-4	37.4 (26.5-48.3)	2.01 (0.91-3.11)	
	PG26N + 39 L/ha NS 24-4	42.5 (27.0-58.1)	2.44 (1.13-3.75)	
Atlantis OD	None	0.28 (0.17-0.39)	0.08 (0.06-0.10)	0.09 (0.07-0.11)
	13 L/ha NS 24-4	0.23 (0.17-0.29)	0.06 (0.05-0.08)	0.12 (0.08-0.15)
	39 L/ha NS 24-4	0.24 (0.16-0.32)	0.05 (0.04-0.06)	0.18 (0.09-0.27)
Cossack OD	None	0.15 (0.08-0.21)		0.04 (0.03-0.05)
	13 L/ha NS 24-4	0.22 (0.17-0.26)		0.08 (0.05-0.11)
	39 L/ha NS 24-4	0.36 (0.25-0.48)		0.11 (0.08-0.15)

References

Mathiassen, S. K. (2017). Effects of new adjuvants, N32 and pH of the spray solution on herbicide efficacy. In: L. N. Jørgensen, B. J. Nielsen, P. K. Jensen, S. K. Mathiassen, S. Sørensen and T. Heick (eds.). Applied Crop Protection 2016, DCA report no. 94, pp. 119-123.

VIII Influence of weed growth stage and moisture stress on the efficacy of glyphosate

Solvejg K. Mathiassen

In Denmark few herbicides are available for weed control in potatoes, with only pre-emergence herbicides authorised for broadleaf weed control. Glyphosate in a tank mix with a residual herbicide is often used pre-emergence to control early flushes of weeds. However, reports from potato growers claim that the efficacy of glyphosate is variable. Two plausible explanations for differences in the susceptibility of weeds to glyphosate were tested: 1) different growth stages and 2) drought stress. The results indicate that differences in growth stages at the early development stages can explain some of the variability in the efficacy of glyphosate in potatoes, for example we found a 2.5 to 3.8-fold increase in the ED_{90} doses at BBCH 12-13 compared to the cotyledon stage. Responses to moisture stress was measured in four experiments with one significant response, a tendency to reduced activity found in two experiments and one experiment with no change. The results indicate that severe moisture stress at spraying can - but does not necessarily - have an adverse effect on glyphosate activity.

Weed control in potatoes relies on a small number of herbicides with the herbicides used for broadleaf weed control only authorised for pre-emergence application. Early flushes of weeds are often controlled with glyphosate in combination with a residual herbicide pre-emergence of the crop. Reports from the potato growers claim that the efficacy is variable. Although the weeds are quite small at the time of application, differences in the susceptibility at these early growth stages may account - at least partly - for these variable effects. Another factor that might play a role is the soil moisture. Potatoes are cultivated on sandy soils, and the mechanical soil cultivation carried out prior to planting reduces moisture stored in the upper soil layer. It is well known that herbicide performance is generally reduced on moisture-stressed plants.

The objectives of these experiments were to examine: 1) the influence of weed growth stage and 2) the influence of moisture stress on the efficacy of Roundup Flex (480 g/L glyphosate). The experiments were carried out on two weed species commonly found in potato fields: oilseed rape (*Brassica napus*) and black bindweed (*Polygonum convolvulus*).

Material and methods

The influence of growth stage

To examine the effect of growth stage in oilseed rape, seeds were sown in 2-L pots in a potting mixture consisting of sand, soil and peat including all necessary micro- and macronutrients. Groups of pots were sown at 4 to 5-day intervals in order to obtain plants with different growth stages which could all be sprayed on the same day. After seedling emergence, the number of plants per pot was reduced to four. A similar experiment was conducted on black bindweed. The germination of seeds of this species is often low and uneven, and in order to generate uniform plants the seeds were sown in trays in the glasshouse and the seedlings transplanted to 2-L pots (3 plants per pot). This procedure was also repeated at 4 to 5-day intervals in order to obtain groups of plants with different growth stages. All plants were grown outdoors.

The two experiments with oilseed rape were sprayed on 2 July (experiment 1) and 3 August (experiment 2); the experiment with black bindweed was sprayed on 26 June (experiment 3). Herbicide application was carried out in a spray cabinet. Each treatment was applied at six to eight doses in a spray volume of 160 to 180 L/ha. The doses on oilseed rape ranked from 7.5 to 720 g/ha and on black bindweed from 7.5 to 240 g/ha with three replicates per treatment.

The influence of soil moisture

The experiments examining the influence of moisture stress were conducted on oilseed rape (2 experiments) and black bindweed (2 experiments). Both species were established as described above. The pots were watered from below until the cotyledon stage. Then moisture stress was induced by turning off the water supply for groups of pots. At the same time the number of plants per pot was reduced to three. All test plants were grown outdoors.

The moisture stress experiments on oilseed rape were sprayed at the 2-4 leaf stage (experiment 4 on 26 June and experiment 5 on 6 July). The black bindweed was sprayed at the 2-3 leaf stage (experiment 6 on 6 July and experiment 7 on 17 August). In each of the experiments six doses of glyphosate were applied, ranking from 11.3 to 720 g/ha. Watering of the moisture-stressed plants was restarted three days after herbicide application.

The plants from all the experiments were harvested two to four weeks after spraying. Fresh and dry weights were recorded. A dose-response model was fitted to the data and ED_{90} doses were estimated.

Influence of growth stages

The growth stages of oilseed rape varied from BBCH 10 (cotyledon stage) to BBCH 14 (4 leaf stage) at spraying (experiments 1 and 2) while the growth stages of black bindweed in experiment 3 varied from BBCH 10 to BBCH 12 (2 leaf stage) at spraying. Photos of the weeds prior to spraying are shown in Figures 1 and 2.

Figure 1. Growth stages of oilseed rape at spraying (experiment 1). From left to right: BBCH 10, BBCH 11.5, BBCH 12, BBCH 13.5 and BBCH 14.

Figure 2. Growth stages of black bindweed at spraying (experiment 3). From left to right: BBCH 10, BBCH 10.3 and BBCH 12-13.

The susceptibility of oilseed rape to glyphosate was similar across the two spraying dates except for the cotyledon stage for which the ED_{90} was 12 g/ha glyphosate in experiment 1 and 22.9 g/ha in experiment 2 (Table 1). In both trials the plants were significantly more tolerant to glyphosate after the 2 leaf stage (>BBCH 12) compared to the cotyledon stage with dose requirements for a 90% reduction of biomass increasing by a factor 3.8 in experiment 1 and 2.4 in experiment 2. A very large increase in ED_{90} at BBCH 14 was observed in experiment 1. On black bindweed, a 3-fold increase in the ED_{90} dose was required when plants developed from the cotyledon stage to the 2-3 leaf stage. Overall, the ED_{90} doses for both weed species were quite low as is often seen in pot experiments. The required doses in the field are higher but experience from previous experiments shows that the ratio between dose requirements at the different growth stages can be transferred to the field. These results indicate that differences in growth stages at the early development stages can explain some of the variability in the efficacy of glyphosate in potatoes as exemplified by the 2.5 to 3.8-fold increases in the ED_{90} doses at BBCH 12-13 compared to the cotyledon stage for both weed species.

Table 1. Estimated ED_{90} doses (g/ha) of glyphosate applied at different growth stages of oilseed rape and black bindweed. Brackets show 95% confidence intervals. N.d.= not determined.

Growth stage	Oilseed rape		Black bindweed
	Experiment 1	Experiment 2	Experiment 3
BBCH 10	12.0 (10.1-13.9)	22.9 (19.4-26.4)	34.9 (7.6-42.1)
BBCH 10.3	n.d.	n.d.	34.5 (25.7-43.3)
BBCH 11.5	33.0 (27.2-38.9)	26.6 (23.1-30.0)	n.d.
BBCH 12	35.7 (29.1-42.3)	38.9 (34.0-43.9)	107.4 (98.0-116.8)
BBCH 13.5	45.2 (35.5-54.9)	54.3 (46.8-61.7)	n.d.
BBCH 14	167.1 (112.5-221.7)	n.d.	n.d.

Influence of soil moisture

The oilseed rape grown at low soil moisture suffered severely from moisture stress at spraying. At the time of application the leaf area of the moisture-stressed plants was reduced by 73% and their fresh weight was reduced by 78%. The leaves of plants growing at low soil moisture were more upright and the colour of the true leaves was darker green. Photos of the oilseed rape plants are shown in Figure 3.

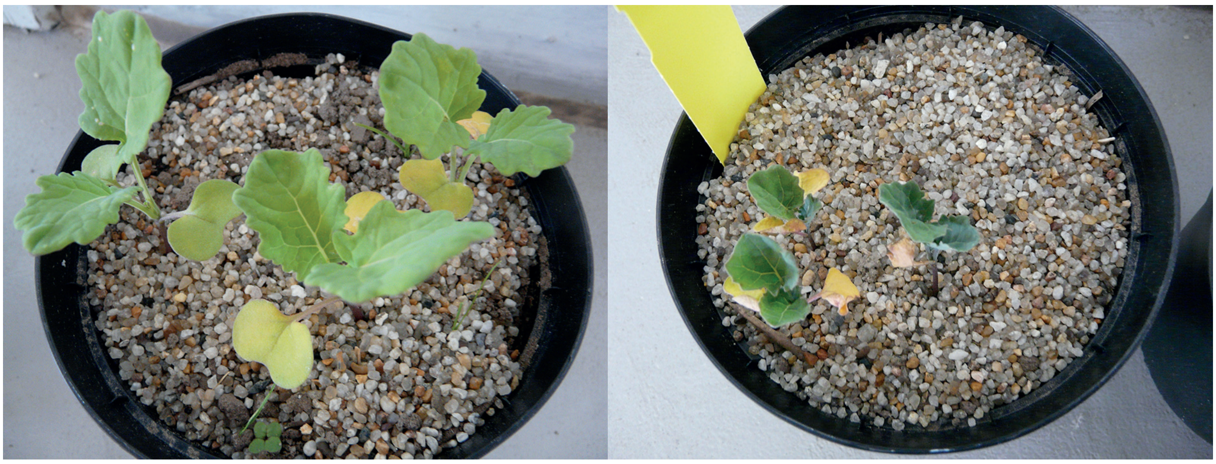


Figure 3. Oilseed rape growing at optimum (left) and low (right) soil moisture conditions (experiment 4).

Table 2. Estimated ED_{90} doses (g/ha) of glyphosate on oilseed rape growing at optimum or low soil moisture. Brackets show 95% confidence intervals. N.d.= not determined.

Soil moisture	Experiment 4 BBCH 12	Experiment 5 BBCH 13-14
Optimum	184.7 (144.8-224.6)	226.0 (165.9-286.1)
Low	228.9 (181.1-275.9)	346.0 (275.8-416.3)
Low, water applied 4 hours after herbicide application	157.5 (126.2-188.8)	n.d.

The dose demand was higher on oilseed rape growing at low soil moisture levels compared to plants well supplied with soil moisture. The ED_{90} doses increased by a factor 1.2 and 1.5 in experiments 4 and 5 respectively, but the differences were not significant (Table 2). In experiment 4, a group of plants suffering from low soil moisture at spraying were supplied with water a few hours after spraying, and the response of these plants to glyphosate was apparently similar to the response of plants growing at optimum moisture conditions during the entire experiment.

The results of moisture stress on black bindweed varied in the two experiments with no differences in responses to glyphosate on optimally watered and drought-stressed plants in experiment 6 and a significant reduced effect of glyphosate on plants growing at low soil moisture in experiment 7 (Table 3).

In general, plants growing under low soil moisture conditions have smaller leaves, develop thicker cuticles and excrete more wax than plants grown under adequate moisture conditions. Such changes in size and surface characteristics may influence both herbicide retention and uptake. In addition, low soil moisture can also reduce the translocation of herbicide within the plants. In this study, a significant response to low soil moisture was found in experiment 7, a tendency to reduced activity in two experiments (experiments 4 and 5) and no change in response was found in experiment 6. The results indicate that severe moisture stress at spraying can - but does not necessarily - have an adverse effect on glyphosate activity.

Table 3. Estimated ED_{90} doses (g/ha) of glyphosate on black bindweed growing at optimum or low soil moisture. Brackets show 95% confidence intervals.

Water status	Experiment 6 BBCH 13	Experiment 7 BBCH 12
Optimum	137.5 (79.6-195.3)	43.3 (35.9-50.6)
Low	118.1 (70.4-165.8)	87.0 (69.3-104.7)

In conclusion, these results support that growth stages and moisture stress can have an effect on glyphosate performance; however, these factors alone are considered insufficient to account for the variability seen in potato fields across Denmark.

Acknowledgement

I would like to thank Gaylene Somerville for valuable comments on the paper.

IX Longevity of seeds of blackgrass following different stubble cultivation treatments

Peter Kryger Jensen

Blackgrass (*Alopecurus myosuroides)* is primarily a winter annual grass weed typically found in crop rotations with a high proportion of winter cereals in areas of the country with clayey soil types. Blackgrass is considered an increasing problem in grass seed production. Herbicide resistance is a significant problem, and a robust and resilient control strategy has to rely on a combination of chemical and non-chemical control methods. Efficient handling of blackgrass seeds can contribute to this goal. The purpose of the present study was to test the influence of different stubble treatments on the longevity of newly shed seeds of blackgrass. Two types of experiments were conducted, a field experiment using normal tillage implements and a small plot field experiment simulating the influence of various tillage treatments on placement of seeds in the soil profile. In the experiment simulating tillage treatments, samples of seeds were placed at distinct soil depths and the longevity of the seed samples following these treatments was assessed. In the field experiment using relevant tillage implements the working depth of the implement was controlled but the influence on the placement of the seeds in the soil profile following the treatment was not assessed. However, assessing blackgrass seedling emergence and longevity in the two types of studies gives an indication of how seed incorporation in the soil profile is influenced by the tillage implements. In both experiments newly harvested seeds of blackgrass were used. Both experiments were replicated two times in 2017 and 2018.

The field experiments were carried out in a stubble field after harvest of winter barley and removal of the straw. Treatments and assessments in the two years are shown in Table 1.

Table 1. Treatments and assessments in the field experiments.

Activity	2017	2018
Harvest of winter barley and removal of straw	28 July	9 July
Distribution of blackgrass seeds on stubble	28 July	13 July
1st stubble treatment	28 July	13 July
2nd stubble treatment	21 August	14 August
1st count of germinated blackgrass seedlings	20 September	13 September
Glyphosate application to control blackgrass	22 September	13 September
Seedbed preparation	17 October	1 October
2nd count of germinated blackgrass	17 January 2018	21 November

Blackgrass was sown in the stubble at a rate corresponding to approximately 200 seeds per m^2. The different stubble treatments included in the field trial are shown in Table 2. The implements used for stubble treatment and seedbed harrowing are shown in Photos 1-3. The seedbed preparation can be carried out a few days after the glyphosate application in September. However, due to the wet autumn in 2017 and very dry conditions in 2018 this treatment was delayed in both years. The seedbed treatment in October included driving with either a seedbed harrow or a direct drilling machine but without sowing of a crop. Seedlings of blackgrass were counted two times in the experiments (Tables 3 & 4). The first assessment in mid-September showed the influence of the stubble cultivation treatments on the establishment of blackgrass seedlings, and the late assessment in January (2018) and November (2018), respectively, was taken as an indicator of the effect of the stubble cultivation treatments on the longevity

Seedbed harrow.

Stubble harrow.

Flex-tine weeder.

of blackgrass seeds. The main conclusion from the results of the first assessment date in 2017 (Table 3) is that there was a reduced number of plants in treatments with stubble harrowing at 5 and 10 cm depth compared to treatments with no cultivation at all and the shallow treatments with the flex-tine weeder. This is probably caused by a deeper incorporation of a proportion of the seeds by the stubble harrowing. The results of the second assessment in January show very small numbers of blackgrass generally and only small and non-significant differences between most treatments. The density of seedlings at this assessment date is taken as an indication of the longevity of blackgrass seeds following the different stubble treatments. The density was, however, generally very low and therefore no significant differences between stubble treatments were found. In the 2018 trial, a larger number of blackgrass seedlings were counted at the first assessment in mid-September following all treatments. However, there was again a larger number of plants in treatments without any stubble tillage or treatments with superficial soil tillage with the flex-tine weeder and a significantly lower density of blackgrass following all treatments with the stubble harrow, indicating a deeper incorporation of at least a fraction of the seeds. The results of the second assessment in November 2018 show the lowest number of blackgrass following the treatment without any stubble tillage and the treatments using the flex-tine weeder at 1-2 cm depth. Larger numbers were counted in treatments with stubble harrowing and with deep flex-tine weeding.

It is supposed that some dormant seeds are remaining in the soil, and this would especially be expected following the two deeper stubble cultivations to 5 and 10 cm depth for which the first assessment indicates that a fraction of the blackgrass seeds have been incorporated to a depth from where the seeds cannot establish plants.

Table 2. Stubble treatment – timing, implement and tillage depth.

Treatment number	First stubble treatment immediately after winter barley harvest	Second stubble treatment, approximately 3 weeks after harvest	Seedbed preparation, October
1.	None	None	2 x seedbed harrowing 2-4 cm
2.	2 x flex-tine weeder 1-2 cm		2 x seedbed harrowing 2-4 cm
3.	2 x flex-tine weeder 2-4 cm		2 x seedbed harrowing 2-4 cm
4.	2 x stubble harrowing 5 cm		2 x seedbed harrowing 2-4 cm
5.	2 x stubble harrowing 10 cm		2 x seedbed harrowing 2-4 cm
6.		2 x flex-tine weeder 1-2 cm	2 x seedbed harrowing 2-4 cm
7.		2 x flex-tine weeder 2-4 cm	2 x seedbed harrowing 2-4 cm
8.		2 x stubble harrowing 5 cm	2 x seedbed harrowing 2-4 cm
9.		2 x stubble harrowing 10 cm	2 x seedbed harrowing 2-4 cm
10.	2 x flex-tine weeder 1-2 cm	2 x flex-tine weeder 1-2 cm	2 x seedbed harrowing 2-4 cm
11.	None	None	No-till drilling
12.	2 x flex-tine weeder 1-2 cm		No-till drilling

Table 3. Density of blackgrass seedlings following different stubble cultivations in 2017.

Immediately after harvest (28 July)	Approximately 3 weeks after harvest (21 August)	Seedbed mid-October (17 October)	No. of blackgrass seedlings per m^2 (20 September)	No. of blackgrass seedlings per m^2 (17 January)
None	None	Seedbed harrow 2-4 cm	9.0	1.0
Flex-tine weeder 1-2 cm		Seedbed harrow 2-4 cm	3.5	0.5
Flex-tine weeder 2-4 cm		Seedbed harrow 2-4 cm	6.5	1.0
Stubble harrow 5 cm		Seedbed harrow 2-4 cm	3.5	0.5
Stubble harrow 10 cm		Seedbed harrow 2-4 cm	2.0	2.0
	Flex-tine weeder 1-2 cm	Seedbed harrow 2-4 cm	9.0	1.5
	Flex-tine weeder 2-4 cm	Seedbed harrow 2-4 cm	9.0	4.0
	Stubble harrow 5 cm	Seedbed harrow 2-4 cm	4.0	0.5
	Stubble harrow 10 cm	Seedbed harrow 2-4 cm	5.0	2.5
Flex-tine weeder 1-2 cm	Flex-tine weeder 1-2 cm	Seedbed harrow 2-4 cm	16.0	3.0
None	None	No-till drilling	9.5	3.0
Flex-tine weeder 1-2 cm		No-till drilling	9.5	2.5
LSD (p=0.05)			6.9	3.3

Table 4. Density of blackgrass seedlings following different stubble cultivations in 2018.

Immediately after harvest (13 July)	Approximately 3 weeks after harvest (14 August)	Seedbed mid-October (1 October)	No. of blackgrass seedlings per m^2 (13 September)	No. of blackgrass seedlings per m^2 (21 November)
None	None	Seedbed harrow 2-4 cm	20	4.5
Flex-tine weeder 1-2 cm		Seedbed harrow 2-4 cm	19	6.5
Flex-tine weeder 2-4 cm		Seedbed harrow 2-4 cm	32	10.0
Stubble harrow 5 cm		Seedbed harrow 2-4 cm	7	7.0
Stubble harrow 10 cm		Seedbed harrow 2-4 cm	6	11.5
	Flex-tine weeder 1-2 cm	Seedbed harrow 2-4 cm	21	2.0
	Flex-tine weeder 2-4 cm	Seedbed harrow 2-4 cm	13	8.5
	Stubble harrow 5 cm	Seedbed harrow 2-4 cm	8	2.5
	Stubble harrow 10 cm	Seedbed harrow 2-4 cm	7	2.5
Flex-tine weeder 1-2 cm	Flex-tine weeder 1-2 cm	Seedbed harrow 2-4 cm	26	2.0
None	None	No-till drilling	25	4.0
Flex-tine weeder 1-2 cm		No-till drilling	17	3.0
LSD (p=0.05)			11	5.2

The small plot field experiment was carried out using seeds from the same seed lot. Samples of 400 seeds were counted and placed either at the soil surface or buried at different depths. This was done in the first week of August in the 2017 trial and in mid-July in the 2018 trial. Two treatments included placement of the seeds at the soil surface. In the first treatment seeds were left directly at the soil surface, whereas in the second treatment a shallow harrowing was carried out with the fingers to mimic shallow soil tillage. The treatments with placement of seeds at the soil surface were carried out in small pots, whereas the treatments including burial at different depths were carried out using samples with seeds mixed with soil and placed in fabric mesh bags. By the end of September all samples were collected from the field and a germination test was carried out in the laboratory. During the germination test soil samples were kept moist to ensure optimal conditions for germination. The number of germinated seedlings was counted when emergence ceased, and this figure is taken as an indication of the influence of the various field treatments on the longevity of blackgrass seeds. The results of the two years were very similar (Figures 1 & 2). The lowest viability was found in seeds left at the surface and there was no significant influence of finger harrowing. Viability was generally much higher in incorporated seeds compared to seeds at the soil surface, and seeds incorporated to just 1 cm depth had a much higher viability than seeds placed at the soil surface. Obviously it seems that the "finger harrowing" had a limited influence on seed placement and hence longevity.

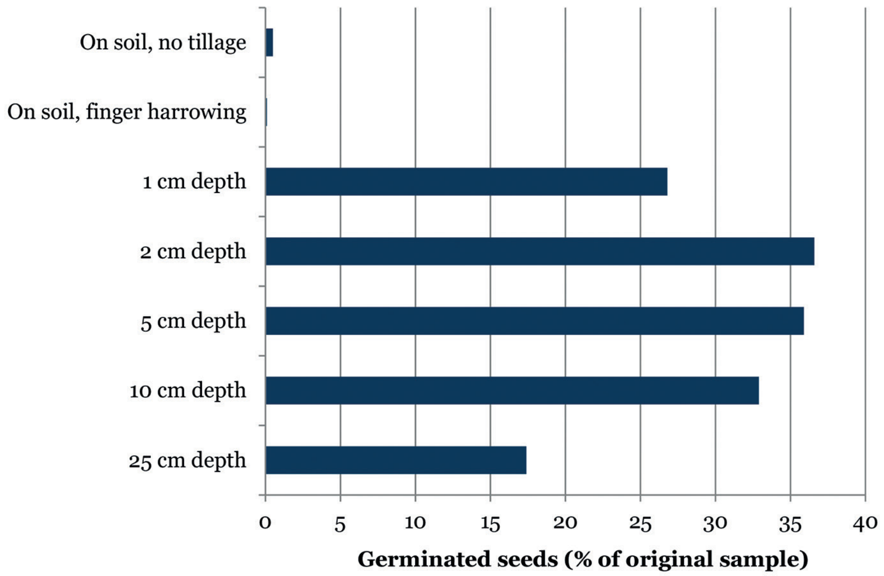


Figure 1. Germination of seeds of blackgrass from samples kept at different soil depths in the field from the beginning of August to the end of September 2017. The figure shows the number of plants in the germination test as a percentage of the original seed sample. LSD = 7.5.

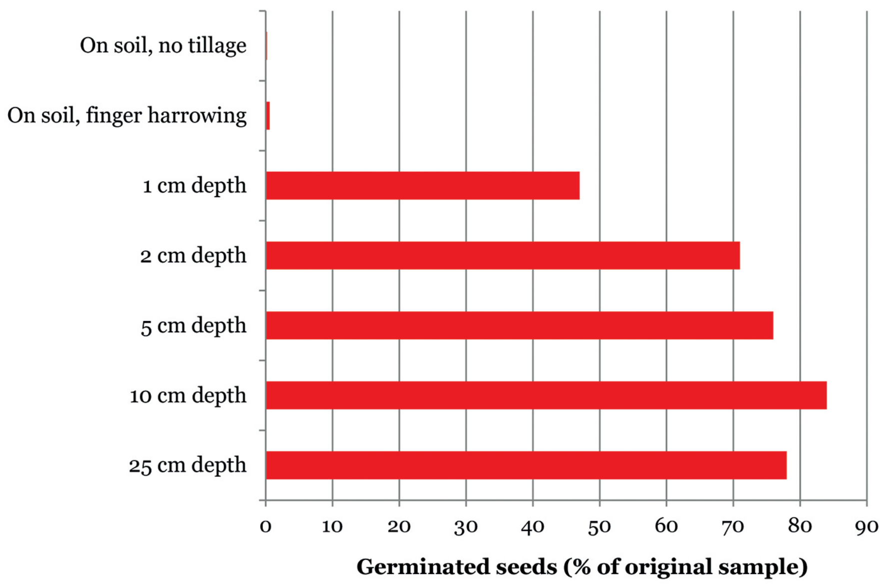


Figure 2. Germination of seeds of blackgrass from samples kept at different soil depths in the field from mid-July to the end of September 2018. The figure shows the number of plants in the germination test as a percentage of the original seed sample. LSD = 3.6.

Conclusion

The results of the two types of experiments conducted in 2017 and 2018 are parallel and support the general conclusion that a stubble treatment strategy can have a large influence on the persistence of newly shed seeds. The longevity of blackgrass seeds was very limited at the soil surface. When seeds were incorporated, a much higher percentage of the seeds survived. An important question is how superficial stubble treatments influence incorporation of seeds and hence longevity. The experiment with full-scale tillage implements as well as the experiment with simulated “finger harrowing” showed that there was no negative influence of a shallow tillage probably because neither the “finger harrowing” nor the flex-tine weeder incorporates the seeds. The full-scale field experiments indicate that stubble harrowing incorporates a fraction of the seeds deeper into the soil and hence incorporates this fraction of seeds into the more persistent seed bank.

The same conclusion was seen in 2015-2016 testing longevity of seeds of Italian ryegrass.

X Results of crop protection trials in minor crops in 2018

Peter Hartvig, Andrius Hansen Kemezys, Louise Hjelmroth, Lis Madsen, Magnus Gammelgaard Nielsen, Kaspar Ingvordsen & Malthe Oksen Adserballe

In 2018 the minor crops group at AU Flakkebjerg carried out 69 field and greenhouse trials. These trials were distributed over 25 trials in vegetables, 12 trials in fruit and berries, 12 trials in garden seeds and 5 trials in nurseries and at golf courses. In addition, there were 12 greenhouse trials (mainly ornamentals) and 3 insecticide trials in agricultural crops, which also belong to the group's activities.

The group's activities are especially characterised by comprising many different crops but also all the common subjects within crop protection, that is to say control of weeds, diseases and pests as well as growth regulation. It is also against this background that there are many different stakeholders behind the trials, which are broadly financed by various agricultural tax funds, GUDP, agrochemical companies and various private trial partners. The Swedish minor use project under LRF has also been a major client and collaborator in the past few years.

The range of traditional chemical crop protection products has for several years become smaller and smaller, and this development seems especially evident in the minor crops. Although Denmark is located in the North Zone together with areawise large countries like Sweden and Finland (and the Baltic States), agricultural production is small, and the market for crop protection products for minor crops is not of that much interest for the agrochemical companies. Therefore, we often see that if a product does not also have an agricultural use/authorisation that ensures a certain sale, then there is a major risk that it will disappear from the market. In other cases, it is also often seen that products on re-registration only keep the agricultural authorisation for products previously used in both agricultural and minor crops.

Because of this development, the group's activities have become increasingly characterised by the growing interest in products with a microbiological or another alternative effect - an interest shared by the industry and certain companies. There is also a great interest in products which have an effect on pests but which are not registered as crop protection products. This includes products on the Basic substances list but also for instance fertilisers or so-called plant enhancers. Within weed control there is an awareness that the times when chemistry could handle everything are over and that it is necessary to supplement with other forms of weed control.

However, the testing of chemical solutions is still the major activity in the trial unit, and a summary of the most important activities is presented below.

Weed control in vegetables in 2018

The trials in weed control in vegetables were mostly a continuation of the trials from the previous year's trials with minor changes in the previous study plans. The majority of the weed control trials in 2018 were again carried out for the Swedish minor use project under LRF. Especially the Swedish onion and carrot growers have been badly affected by the changes in the range of herbicides. As some within the industry will know, the loss of Stomp and Totril has been a theme in the trials for some years. But whereas we in Denmark still have access to Stomp, and whereas Totril has been replaced by Xinca (bromoxynil), the situation in Sweden is different as Stomp probably will not get an authorisation again, and at the same time it is very uncertain whether there will be any bromoxynil products in the EU at all. Furthermore, the dose rate of Fenix has been severely reduced so that a maximum of 0.9 litre per hectare is permitted, which is considerably less than the dose rate previously permitted for use to especially the carrot and parsnip growers.

Herbicide strategy trial in parsnips in Peppinge, Sweden. The trial area was dominated by hairy nightshade, *Solanum physalifolium*. The field trial in Sweden indicated fluroxypyr to control the hairy nightshade effectively. However, fluroxypyr causes also much damage to the parsnips, and the use of precise timing, dose rates and/or split strategies is often a way of using the existing herbicides safely and efficiently in weed control in vegetables.

The Danish activities concerning weed control in vegetables have mainly been concentrated in the GUDP project HORTPROTECT including work with direct sowing and strip tillage in onion, beetroot and cabbage. Another element in the project is testing of row-differentiated weed control, that is to say different weed control within the row (intra-row) and in the space between the rows (inter-row). The testing includes a dual band sprayer allowing intra-row spraying with a selective herbicide and at the same time making a shielded inter-row spraying.

Weed control in garden seeds in 2018

Denmark's status as the world's largest producer and exporter of spinach seeds is a contributing factor for the industry to be continuously on the lookout for new herbicides or ways of controlling weeds. Another contributing factor is that there is still an ongoing search for a replacement for Asulox, which is a key herbicide in spinach growing. Besides a number of trials in spinach, weed trials in 2018 were also carried out in pak choi and cress for seed production.

Herbicide screening trials using a 'small plot' sprayer in onions, carrots and spinach in 2018

A specially designed sprayer for 'small plots' allows us to screen a great number of different herbicides in a relatively small area. The area of each plot is usually 1 m^2 and it is a very efficient way of screening for potential herbicides that could be used in the future in traditional field trials. A number of test herbicides were used in three different crops: onions, carrots and spinach. Interestingly, none of the tested herbicides were causing any considerable damage on onions when applied before emergence of the onions. The post-emergence applications of a number of different test herbicides showed no or very little damage to the onions, even though they are known to cause some phytotoxic symptoms. This could be explained by onions having an extraordinarily thick wax layer this year due to warm and sunny weather conditions, and the results should be interpreted taking this into account.

The pre-emergence applications of the test herbicides in carrots and spinach showed almost no damage either, while the post-emergence application of a great number of test herbicides showed great damage. The herbicides that caused the least phytotoxic damage will be evaluated and possibly included in the traditional field trials for further testing.

Herbicide screening trials using ‘small plots’ - an efficient way of screening for potential herbicides that could be used in the future in traditional field trials.

Alternatives to diquat

The EU Commission has decided not to renew the approval of diquat based on concerns related to the exposure of bystanders, residents and birds. Member states will need to withdraw authorisations for products containing diquat by 4 May 2019 at the latest. There will then be a grace period - the length of which is to be decided by each member state - to allow use-up of the products, which itself must expire by 4 February 2020 at the latest. Diquat is widely used in minor crops for weed control and as a desiccant before harvest. Diquat is used as pre-emergence of the crop treatment in a number of seeded vegetables and as a shielded band (inter-row) application in plant nurseries, Christmas trees, berries, pome trees and berry bushes. Diquat is also widely used as a desiccant in vegetable seed production.

A number of plant protection products have properties similar to diquat, including products with the active substance pelargonic acid. Pelargonic acid is approved in Denmark, but due to high production costs and the Danish pesticide fee it becomes very expensive and therefore it is doubtful if it can become an alternative to diquat in practice. It is worth mentioning that pelargonic acid is in a very unfavourable situation in the Danish pesticide fee system as the pesticide fee is partially calculated based on the rate of active substance per hectare. The target dose rate of pelargonic acid is often around 10 kg of active substance per hectare, depending on use, and it is considerably higher than most of the active substance rates in plant protection products.

Christmas trees - alternatives to glyphosate

Denmark is the leading exporter of Christmas trees in Europe. Germany and France are the two largest export markets accounting for more than 50% of the Danish Christmas tree export. Some importers in both countries have expressed a demand for 'glyphosate-free' Christmas trees, and as the future of glyphosate in plant protection in the EU is uncertain, the Danish Christmas tree Association's research fund has granted a project to look for alternatives to glyphosate.

Glyphosate is a very important active compound in Christmas tree production and is used in 5 different GAPs in Christmas tree production including spring and autumn applications (over the trees before and after bud burst, respectively), and as shielded application after bud burst. Three trials at different locations on Zealand and Funen were initiated in the autumn of 2018 to evaluate some alternative products as an autumn application after new growth has hardened off. The efficacy results from the early weed control assessments look very promising so far, but the trials are not terminated and the selectivity assessments are to be assessed in the spring of 2019.

Further trials are being planned for spring application over trees before bud burst and as shielded applications in order to evaluate the efficacy and selectivity of the alternatives to glyphosate.

Control of fungal diseases in vegetables in 2018

A number of fungicide trials were carried out for agrochemical companies, while the grower organisation's main priority has been to find an alternative to Acrobat for control of onion downy mildew. This product has for a number of years been the leading fungicide for control of this disease, which - when untreated - can develop at epidemic speed, but the company has withdrawn the product from the Danish market. The attempts at finding alternatives have been going on for some years, but since 2016 the trials have been carried out at Flakkebjerg with artificial inoculation. Even though this trial method has so far proved a good way of ensuring the presence of the wanted pest in the trials, the growing season 2018 was very dry and warm, and the artificial inoculation failed to induce downy mildew in the onion trial.

Control of fungal diseases in spinach in 2018

As mentioned above, Denmark is the world's largest producer and exporter of spinach seeds, and the area will in the coming season exceed 12,000 hectares. Weeds are a major challenge in spinach growing, but the humid Danish climate may also cause problems with fungal diseases in some years. To be able to export seeds to the whole world, seeds must be of the absolutely best quality, and therefore the fungal diseases must be controlled in order to protect the seeds against infection, but of course also to ensure yield. So far, many have used a control strategy with a relatively high input of pyraclostrobin and boscalid; this is unfortunate because this practice increases the risk that the fungi develop resistance to these substances. Therefore, there is a major need to develop strategies with other active substances, and this trial work, which is expected to last some years, began in 2016 with a single trial and was continued in 2017 and 2018 with 3 trials each year. As the season was very warm and dry, unfortunately almost no diseases were observed in the field trials, and the trials are going to be repeated next year.

Plant protection trials in greenhouse cultures

The trials with plant growth regulators in greenhouse cultures in 2017 continued in 2018. A number of trials were carried out in the Swedish minor use project. Cycocel has for many years been extensively used for growth inhibition of ornamentals in many countries. However, there is uncertainty concerning the future of the product, and in Sweden there is much to suggest that it will not be re-registered for agricultural use, and that it will therefore no longer be a possibility for use in ornamentals either. In 2016 trials were carried out in 5 different vigorously growing ornamentals, and these trials were repeated in 2017. The results from screening trials in 2016 and 2017 were analysed and 4 new trials were carried out in 2018. Various growth regulation products were tested with rather different results. Some substances work well in one culture but result in damage or have no growth regulatory effect in other cultures. There is also a difference as to whether the products are being drenched at the beginning of the culture period or whether they are being applied by spraying.

Alternative plant protection products for disease and insect control in pot plants and carrots

A part of GUDP HORTPROTECT project included some trials for optimisation of alternative plant protection products in a greenhouse and in open field vegetables. Greenhouse trials were set up with mildew in potted roses as well as with *Fusarium* in potted cyclamen and thrips in strawberries and chrysanthemum. A field trial with *Sclerotinia* in carrots was carried out as well.

Generally, the tested alternative products showed lower disease control compared to the reference chemical fungicides, suggesting that they cannot really replace the chemical fungicides. It is, however, expected that the alternative products could be used preventively and be included in Integrated Pest Management with the conventional fungicides.

In the trial with potted roses, the treatment with products AgriColle + Borregaard PK showed the highest disease control of mildew (up to 60-70% efficacy), which was identified as the most outstanding among the tested alternative products.

XI Results from testing of herbicides, growth regulators and desiccants in agricultural crops in 2018

Steen Sørensen

In 2018 the group responsible for herbicide testing in agricultural crops at AU Flakkebjerg carried out 50 field trials. They comprised 28 trials in cereal crops, most of which were carried out as spring treatments, 7 trials in seed grass, 4 trials in maize, 7 trials in permanent grass/grass fields and 4 other trials. As most of the herbicide trials in agricultural crops were carried out as confidential trials, the results shown below are solely results of the growth regulation trials in cereal crops.

Materials and methods

All testing trials are carried out as field trials. Most are located at farmers' fields in order to meet specific demands regarding soil and especially weed flora, but a small number of trials are located at AU Flakkebjerg's own fields; all trials are located in South, West or Northwest Zealand. All trials are carried out as GEP trials with 4 blocks and according to EPPO guidelines. The trials are carried out as either tolerance/yield trials or efficacy trials, but both effect and tolerance are recorded in the growth regulation trials. When the efficacy trials are laid out, the aim is to target areas with considerable weed populations in the form of many weed species or to meet the wishes for "target weed" species in the individual trials. In the tolerance/yield trials there is usually a wish for weed free areas, but as this is not always possible, some sort of basic treatment is carried out or the area is weeded mechanically or by hand.

In all the trials in the agricultural crops a self-propelled trial sprayer is used, which as standard is equipped with a Hardi LD015 nozzle. Normally, 150 L of water per hectare and a pressure suitable for a driving speed of 4.5 km/h are used.

All trials are assessed according to EPPO guidelines, but there is a growing tendency that the contractor of the trials draws up requirements for assessments and time intervals that extend beyond EPPO guidelines. Our aim is as far as possible to follow the guidelines described in the protocol for the individual trials.

Assessments were made of crop damage and lodging from the time of treatment until harvest in the growth regulation trials; the plant height and the yield were also measured in these trials.

Introduction and purpose

In 2018 4 growth regulation trials were carried out in cereals, 2 in winter wheat and 2 in spring barley. The purpose of the trials in winter wheat was to compare the effect of Trimaxx, either as a single treatment or in a tank mix with Stabilan Extra, Cerone, Moddus M or Medax Top + ammonium sulphate at 2 timings. In spring barley the purpose was to compare the effect of Trimaxx with Moddus M, Medax Top + ammonium sulphate and Cerone. The treatments in winter wheat were carried out in the spring of 2018 when the winter wheat was at stage 30.0-30.8 BBCH and at stage 37 BBCH; in spring barley the treatment was carried out when the spring barley was at stage 37 BBCH.

Results

There was no visible damage to the crop following the treatments in either winter wheat or spring barley, nor was there any lodging in any of the trials. The measurements of height, carried out at stage 75-77 BBCH and at harvest, showed only a small reduction of the plant height in comparison with untreated; in winter wheat the reduction was greatest following the treatments with Medax Top + ammonium sulphate and Trimaxx + Cerone; in spring barley the reduction was greatest following the treatment with Cerone.

In all trials the yield from the treatments was a little lower than or at the same level as in untreated. However, in the winter wheat trials there was a great difference in yield in the 2 trials; in one trial the yield level for the year was very high. In both trials the lowest yields came after the treatment with Medax Top + ammonium sulphate. However, there were no significant differences in yield in the trials.

In the spring barley trials the yields were very low especially in one trial; this was probably caused by drought. The highest yields were in both trials found following the treatment with Medax Top + ammonium sulphate; however, there was no significant difference in yield in the trials.

The very dry and hot weather probably influenced the trials so that the effects on lodging, plant height and yield were not obtained that can be expected in an – as far as the weather is concerned – normal year.

Figures 1-8. Results of strategy with plant growth regulators in cereals.

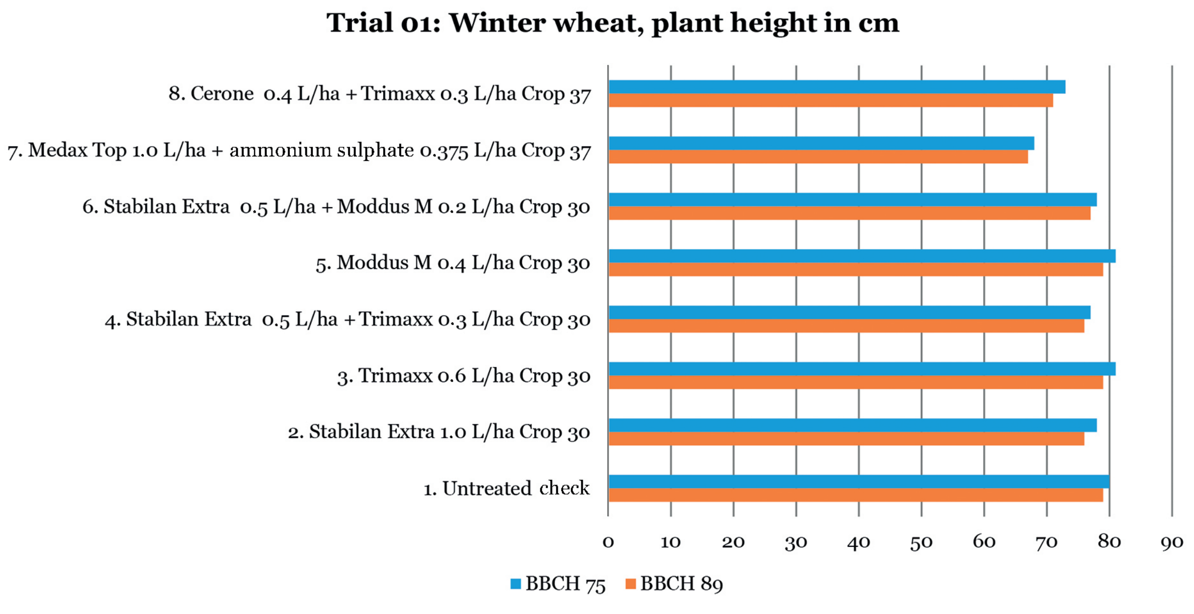


Figure 1. Winter wheat, plant height in cm (trial 180227-01).

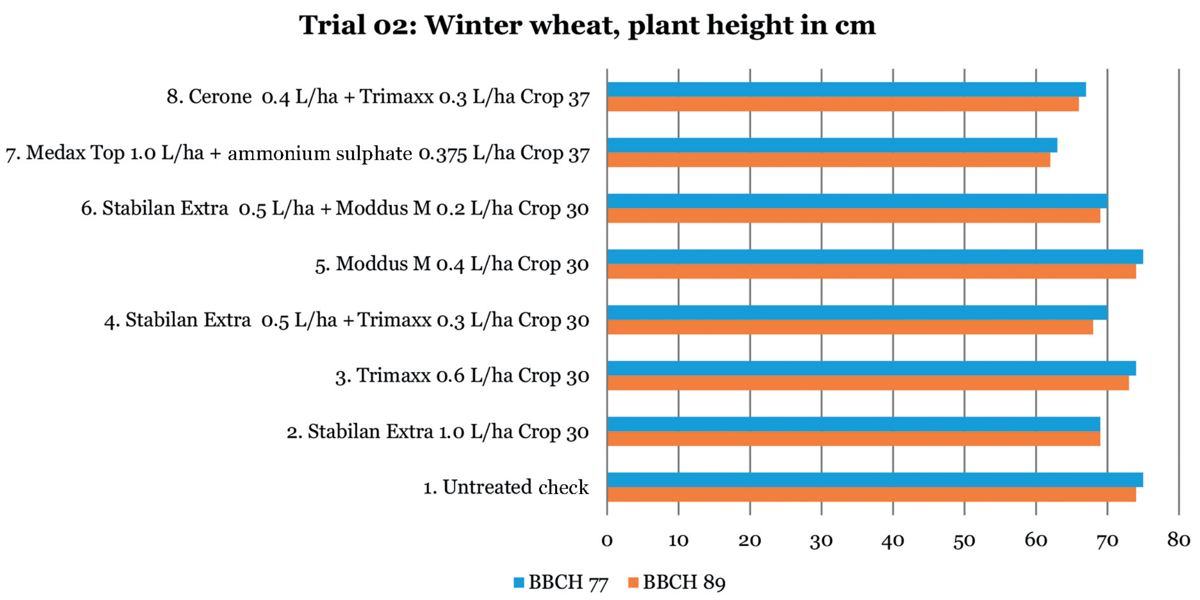


Figure 2. Winter wheat, plant height in cm (trial 18227-02).

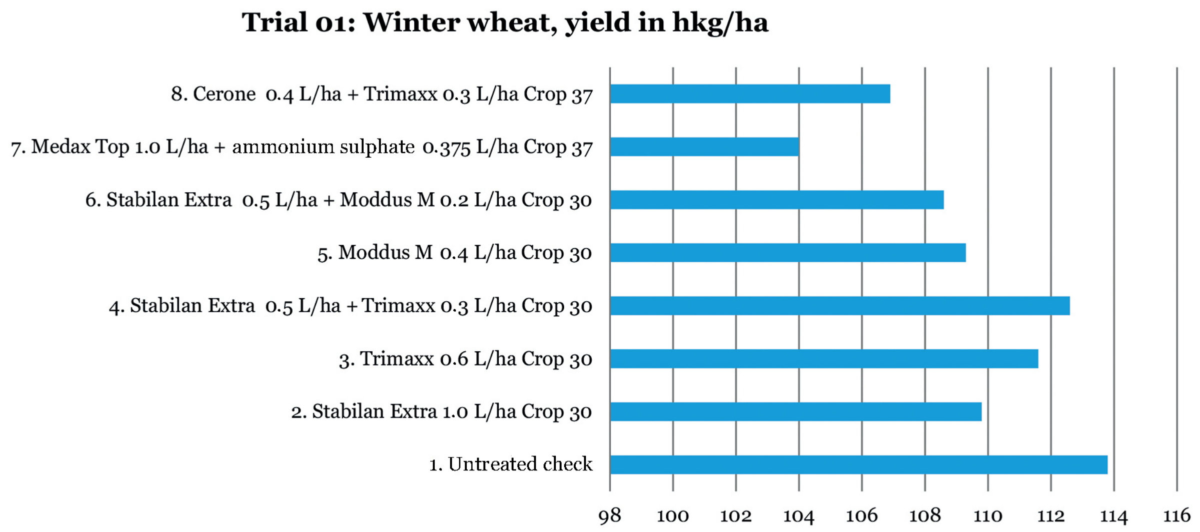


Figure 3. Winter wheat, yield in hkg/ha (trial 18227-01).

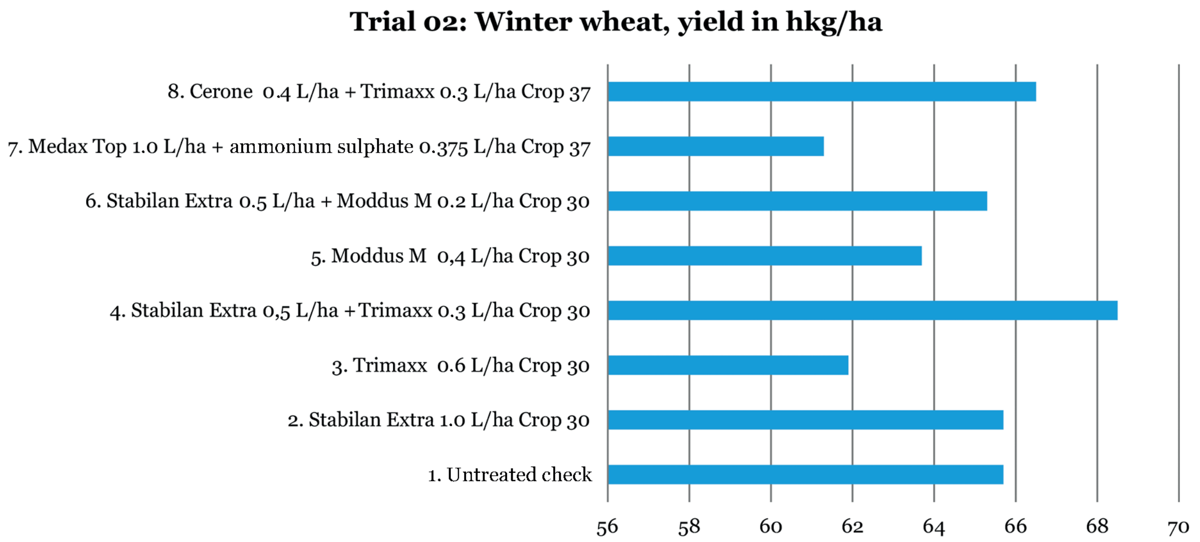


Figure 4. Winter wheat, yield in hkg/ha (trial 18227-02).

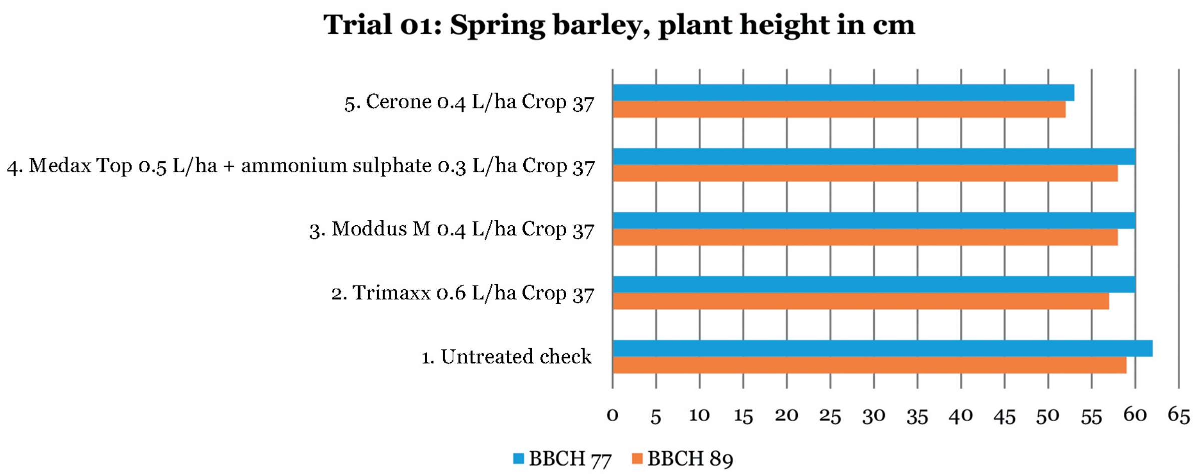


Figure 5. Spring barley, plant height in cm (trial 18056-01).

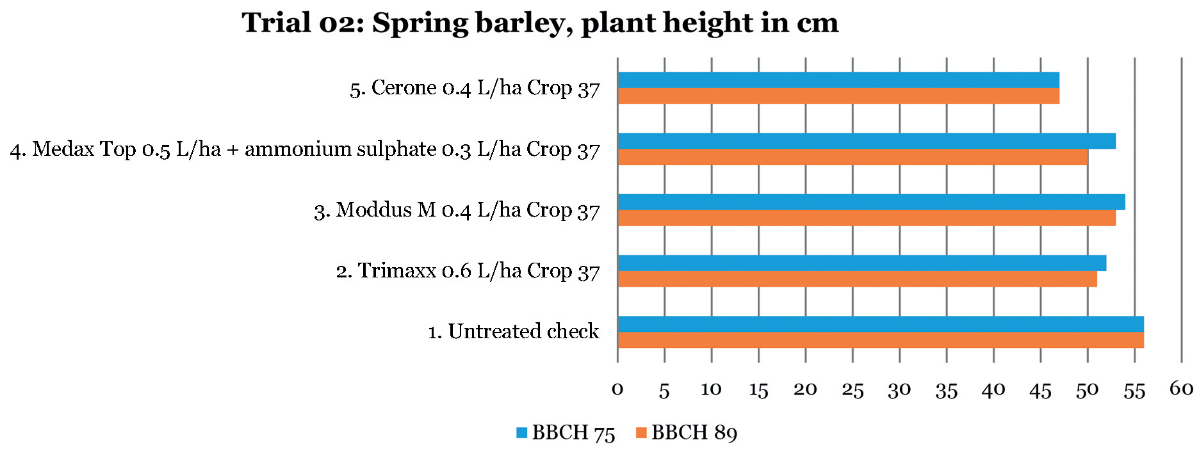


Figure 6. Spring barley, plant height in cm (trial 18056-02).

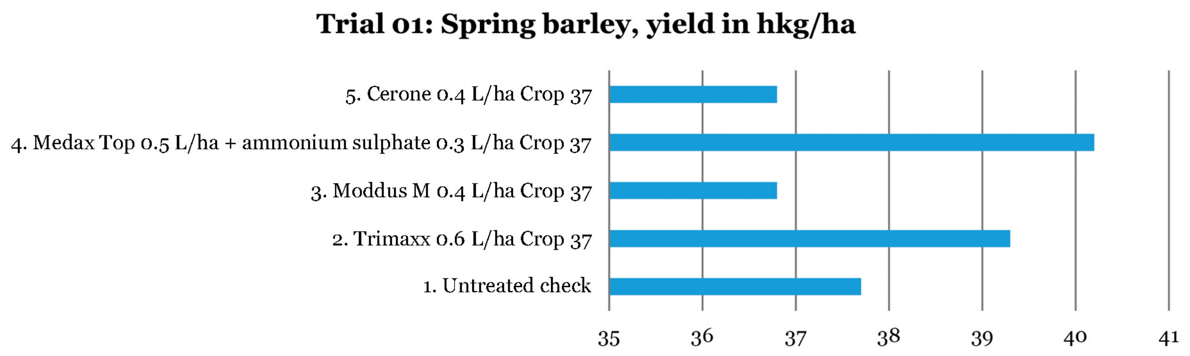


Figure 7. Spring barley, yield in hkg/ha (trial 18056-01).

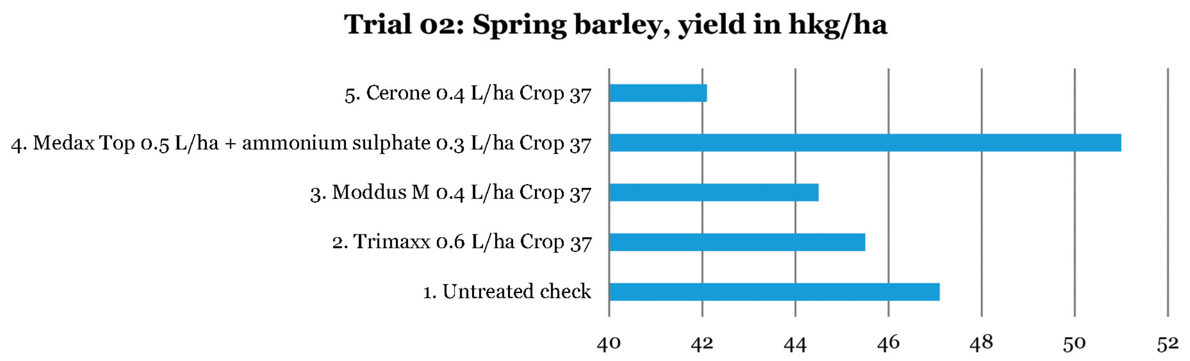


Figure 8. Spring barley, yield in hkg/ha (trial 18056-02).

XII GRRC report: *Puccinia striiformis* race analyses/ molecular genotyping 2018

Mogens Støvring Hovmøller, Julian Rodriguez-Algaba, Tine Thach, Annemarie Fejer Justesen & Jens Grønbech Hansen

Key highlights 2018

- Central Asia/East Africa: **Pst11**, first detected in Central Asia in 2012, became the most prevalent genetic group of yellow rust in East Africa, detected in Ethiopia, Kenya, Rwanda and Tanzania. The recent inter-continental spread into East Africa was confirmed by the presence of only a single race in **PstS11** irrespective of sample origin.
- South America: **PstS13** was completely dominant in both Argentina and Chile, severely affecting both wheat and triticale cultivars. Only one race has been detected in this group, associated with severe rust epidemics on triticale in Northern Europe and durum wheat in Southern Europe.
- Europe: **PstS10**, a.k.a. *Warrior*(-), was the most prevalent group consisting of one dominant genotype. The original Warrior group (**PstS7**) was less prevalent, but spreading to new areas. Additional groups were detected in many countries.
- North Africa: A distinct race (and genotype) in genetic group **PstS14**, first detected in 2016, made up 100% of samples from Morocco, causing severe rust epidemics in 2017. A new unique genotype was observed in Egypt – not previously detected by GRRC.
- Virulence to *Yr5* and *Yr15* was not detected.
- Summary of SSR genotyping and race phenotyping results from GRRC (2008-2018) is available online (http://www.wheatrust.org/), including an updated table showing the relationship between races and genetic groups.

This report presents results mainly based on Simple Sequence Repeat (SSR) genotyping of samples of *Puccinia striiformis* from wheat and triticale collected across four continents in 2018, with a reference to the results from 2017. The testing of additional samples from 2018 is ongoing with emphasis on additional race testing of representative isolates from existing and new genetic groups. Over the years, we have observed a strong connection between genetic group and race which is defined by the pattern of compatible and incompatible interactions between host and pathogen. The race phenotype is considered 'virulent' in case of a compatible interaction, conferred by 'high' infection type scores on one or more host differential lines with a common Yr-gene, and 'avirulent' in case of incompatible interactions conferred by 'low' infection types. Race typing requires access to spore samples of live, pure isolates and strict experimental conditions (Hovmøller et al., 2017; Sørensen et al., 2016). In contrast, SSR genotyping was based on samples of rust-infected plant material without prior recovery and spore multiplication.

As opposed to virulence phenotyping, the SSR genotyping results reveal genetic diversity and relationships within and among genetic groups. Results from previous years are available as pdf files from the GRRC website, where the results are also available on maps and charts.

Nomenclature of races and genetic groups

Common names based on SSR genotyping were assigned to genetic groups and races demonstrating high epidemic potential. The genetic groups were named Pst followed by a digit. Race variants were designated by the additional virulence observed or (-) in case a new variant had fewer virulences than the first defined race within the considered lineage. Race names already adopted by the farming community in Europe were maintained, e.g. *Warrior* and *Kranich*, which are named according to the wheat cultivar where they caused the first confirmed epidemic outbreaks. A comprehensive justification and rationale for the naming of significant *P. striiformis* races and genetic groups has been published (Ali et al., 2017) and an updated summary is available on the GRRC website. The new tools allow the user to highlight particular countries, years and races/genotypes. The occurrence of prevalent races/genotypes is shown on maps in case geographical coordinates have been provided.

Submission and preparation of samples

Prior to submission of rust-infected leaf samples, a request is sent by e-mail to GRRC to obtain an import permit. Information about e.g. host cultivar, sampling date, location and disease severity must be provided for interpretation of results. The details of sampling preparation are given at http://wheatrust.org/submission-of-isolates/. On this page you will find a video demonstrating ideal sampling procedures. Focus sampling areas in 2019 outside Europe will be selected in collaboration with staff at the international centers and NARCs in Africa and Asia, with a focus on high-risk epidemic areas. Bilateral agreement with private/public enterprises is also possible. Since 2011, GRRC has accepted samples of yellow rust, leaf rust and stem rust.

A total of 325 samples from 10 countries in Africa and Asia were handled, each sample generally consisting of multiple rust infected leaves. Subsets were selected for genotyping without prior recovery, whereas the best looking samples were chosen for recovery using a mixture of susceptible seedlings of Cartago, Morocco and Anja (Table 1). Ninety-nine isolates were recovered and further multiplied. Recovery rates varied from case to case, emphasising the importance of optimal handling and preservation of samples, and submission without delay. A total of 267 samples were submitted from 16 European countries (Table 2), and 65 samples from South America were handled. A total of 256 isolates were recovered in 2018.

Several cycles of multiplication were made to obtain a sufficient amount of spores for storage and race analyses. In case of signs of multiple genotypes/races within a sample, these were generally subcultured for purification according to the procedures published in 'Methods and Protocols', open access for downloads for non-commercial and educational purposes. The genotyping of isolates based on DNA extraction from infected leaves (single lesions) was generally successful, following the procedures of Thach et al. (2016). The methodology proved very useful for generating results based on 'original samples' in case of poor recovery and for confirming genetic purity and assignment of races to specific genetic lineages.

Table 1. Number of samples of yellow rust handled in 2018, Africa and Asia.

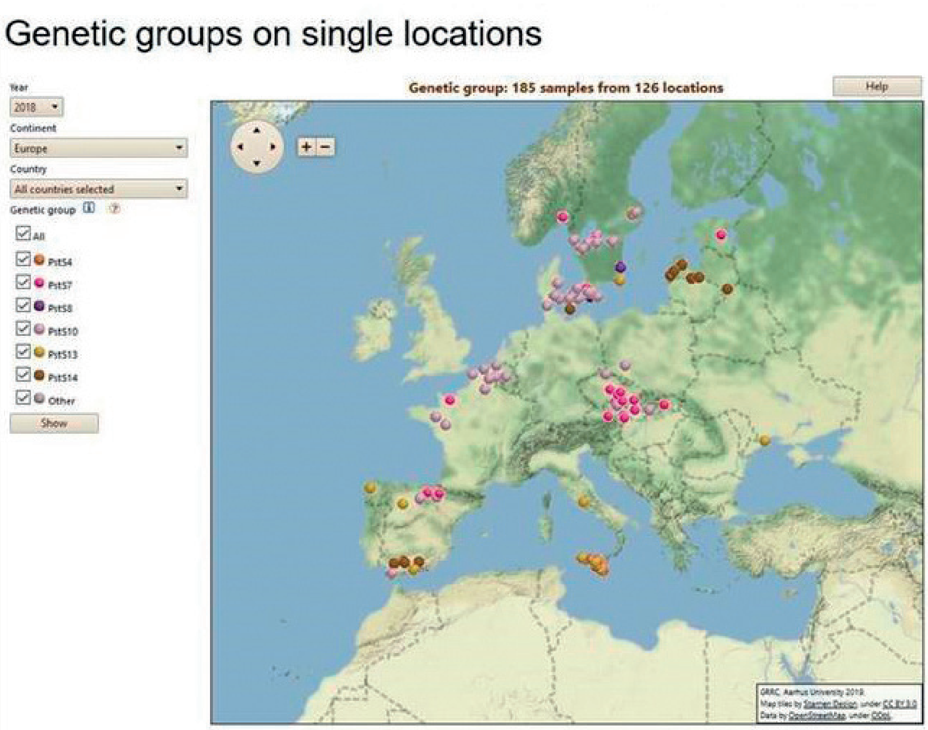
Country	Dead	Recovered	Grand total
Afghanistan	12		12
Egypt	15		15
Eritrea	8		8
Ethiopia	62	19	81
Iran	5		5
Kenya	67	20	87
Morocco	39	27	66
Rwanda	1	8	9
Tanzania	5	1	6
Uzbekistan	12	24	36
Grand total	**226**	**99**	**325**

Table 2. Number of samples of yellow rust handled in 2018, Europe.

Country	Dead	Recovered	Grand total
Austria	2	1	3
Belgium	6	7	13
Czech Republic	22	6	28
Denmark	6	45	51
Estonia	2		2
France	6	4	10
Germany	2	3	5
Italy	34	2	36
Latvia	9	8	17
Netherlands		3	3
Norway	1	6	7
Poland		4	4
Slovakia	7	6	13
Spain	12	12	24
Sweden	15	30	45
Ukraine	6		6
Grand total	**130**	**137**	**267**

Table 3. Number of samples of yellow rust handled in 2018, South America.

Country	Dead	Recovered	Grand total
Argentina	38	4	42
Chile	7	16	23
Grand total	**45**	**20**	**65**



Example of screen shot from the ‘wheatrust.org’ showing geographical locations of genetic groups of wheat yellow rust.

2018 results

A total of 396 samples from 28 countries and four continents were successfully genotyped. In Table 4a,b,c, results are compared with results for the samples from 2017, some of which were finalised in 2018.

Table 4a-c. SSR genotyping of samples of yellow rust collected in 2017 and 2018. Results are shown as number of isolates and frequency. For nomenclature of genetic groups (Pst1-14), see GRRC updated table and Ali et al. (2017). Cross references to significant races and virulences are shown in Table 5. Graphical presentation of results available on www.wheatrust.org. (Continues on the next page).

a) Geographic group	Country	Genetic group	Crop season		Number of isolates, total	% of isolates, total
			2017	2018		
Africa, C&W Asia	Afghanistan	Other		8	8	2.2
	Azerbaijan	**PstS7**	2		2	0.5
	Egypt	Other		2	2	0.5
		PstS1/PstS2*		9	9	2.4
	Eritrea	Other	9	5	14	3.8
	Ethiopia	**PstS11**	48	28	76	20.6
		PstS1/PstS2	9	3	12	3.3
	Iran	**PstS1/PstS2**		3	3	0.8
	Iraq	Other	3		3	0.8
		PstS1/PstS2	6		6	1.6
		PstS3	1		1	0.3
	Kenya	Other	1		1	0.3
		PstS11	13	30	43	11.7
		PstS1/PstS2	4	9	13	3.5
	Morocco	**PstS14**	38	54	92	24.9
	Russia	Other	4		4	11
	Rwanda	**PstS11**		3	3	0.8
		PstS1/PstS2	4	6	10	2.7
	Tanzania	**PstS11**		3	3	0.8
		PstS1/PstS2	4	3	7	1.9
	Uzbekistan	**PstS11**	1		1	0.3
		PstS9	31	25	56	15.2
Africa, C&W Asia, total			**178**	**191**	**369**	**100**

b) Geographic group	Country	Genetic group	Crop season		Number of isolates, total	% of isolates, total
			2017	2018		
S. America	Argentina	**PStS13**	30	17	47	65.3
		PStS14	5		5	6.9
		PstS7	3		3	4.2
	Chile	**PStS13**		17	17	23.6
S. America, total			**38**	**34**	**72**	**100**

*PstS1/PstS2: These two aggressive strains are only distinguishable by SCAR markers (Walter et al., 2016), which have not yet been applied on 2018 samples.

Table 4a-c. (Continued).

c) Geographic group	Country	Genetic group	Crop season		Number of isolates, total	% of isolates, total
			2017	2018		
Europe	Austria	**PstS7**	1	3	4	0.9
	Belgium	**PstS10**	2	10	12	2.6
		PstS7	1	1	2	0.4
	Czech Republic	**PstS10**		3	3	0.7
		PstS7		9	9	2.0
	Denmark	**PstS10**	79	34	113	24.8
		PstS13	15	2	17	3.7
		PstS14	1	4	5	1.1
		PstS7	4	2	6	1.3
		PstS8	6		6	1.3
	Estonia	**PstS7**		2	2	0.4
	France	**PstS10**		4	4	0.9
		PstS7	4	4	8	1.8
		PstS8	2		2	0.4
		Other	1		1	0.2
	Germany	**PstS13**	5	5	10	2.2
	Italy	**PstS10**	3		3	0.7
		PstS13	47	8	55	12.1
		PstS14	1	1	2	0.4
		PstS4	2	16	18	4.0
	Latvia	**PstS10**	5		5	1.1
		PstS13	2		2	0.4
		PstS14	6	9	15	3.3
		PstS4	1		1	0.2
		PstS7	1	2	3	0.7
		Other		1	1	0.2
	Netherlands	**PstS10**	11	3	14	3.1
		PstS13	1		1	0.2
		PstS7	1		1	0.2
	Norway	**PstS10**	17	1	18	4.0
		PstS7	2	1	3	0.7
		Other	2		2	0.4
	Poland	**PstS10**		1	1	0.2
		PstS13	1		1	0.2
		PstS7	2		2	0.4
	Slovakia	**PstS10**		1	1	0.2
		PstS14		1	1	0.2
		PstS7		2	2	0.4
	Spain	**PstS10**		10	10	2.2
		PstS13		4	4	0.9
		PstS14		6	6	1.3
		PstS7		4	4	0.9
	Sweden	**PstS10**	14	23	37	8.1
		PstS12	1		1	0.2
		PstS13	4	3	7	1.5
		PstS14	2		2	0.4
		PstS4	1		1	0.2
		PstS7	5	3	8	1.8
		PstS8	11	4	15	3.3
	Ukraine	**PstS13**		4	4	0.9
Europe, total			**264**	**191**	**455**	**100**

In 2018, **PstS11** was detected in two additional countries in East Africa, Rwanda and Tanzania, now being the most prevalent group in East Africa, in particular in Kenya and Ethiopia. **PstS11** was first detected in Afghanistan in 2012, later spreading to other countries in this region. Only a single race has been detected in **PstS11** (virulence phenotype: -,2,-,4,-,6,7,8,-,-,-,17,-,-,27,32,-,AvS,-), but often associated with new epidemics on previously resistant cultivars in affected areas.

Another genetic group, **PstS14**, containing only a single race, (virulence phenotype: -,2,3,-,-,6,7,8,9,-,-,17,-,25,-,32,Sp,AvS,-) dominated in Morocco, where it made up 100% of samples investigated. This suggests that the race PstS14 may be adapted to many cultivars, and potentially cause large-scale epidemics. *PstS14* was detected in Europe at low frequency, and in 2017 also in South America for the first time. Otherwise, the aggressive strain **PstS1/PstS2** was detected at multiple locations in CWANA, the most frequent race carrying virulence to *Yr27* (Table 5). In Uzbekistan, **PstS9** is by far the most prevalent group (most common virulence phenotype: 1,2,3,4,-,6,-,-,9,-,-,17,-,25,27,32,-,AvS,Amb), which was also the case in 2016-2017. In Eritrea, a specific group not yet assigned a group number was prevalent. We were unable to recover any of these isolates, but it may refer to a *Yr10* and *Yr27*-virulent race prevalent in Eritrea 2002-2011 (virulence phenotype: -,2,-,-,-,6,7,8,-,10,-,-,24,-,27,-,-,AvS,-).

A novel genotype was detected in Egypt, some relationship with **PstS1/PstS2**, **PstS13** and **PstS14**, but additional analyses and live samples are required to make a firm conclusion about origin and epidemic potential. None of the Egyptian 2018 samples could be recovered, possibly due to long time between sampling and lab arrival. It would be valuable to follow up, taking into account the yellow rust outbreaks observed in Egypt in 2018.

In South America, **PstS13** was widespread in Argentina and Chile (Table 4b), where unusual severe and widespread epidemics of yellow rust affected wheat crops in many areas both in 2017 and 2018. Only a single race has been detected in PstS13 irrespective of sampling origin (virulence phenotype: -,2,-,-,-,6,7,8,9,-,-,-,-,-,-,-,-,AvS,-). **PstS13** has been detected in most European countries (Table 4c), including Ukraine in the east, in Northern Europe giving rise to severe epidemics on multiple cultivars of triticale and in Southern Europe affecting durum wheat severely. The race found in the **PstS13** genetic group has also proved highly epidemic on multiple wheat cultivars in Argentina and on triticale in Chile.

PstS10 was the most prevalent group on bread wheat in Europe, so far dominated by a single race (virulence phenotype: 1,2,3,4,-,6,7,-,9,-,-,17,-,25,-,32,Sp,AvS,-). In terms of virulence, this race is almost similar to *Warrior* (**PstS7**), which is present in most European countries, but in lower frequencies than previously. In 2018, the *Kranich* race (**PstS8**) was not detected outside Sweden, but most likely present in other countries at low frequency.

Race typing: Only few isolates of the 2018 samples have so far been race typed, giving priority to molecular genotyping of a high number of samples from countries worldwide. During spring 2019, selected samples representing existing and new tentative genetic groups will enter race typing. Results will be published on www.wheatrust.org. A fully updated summary of prevalent races in each genetic group since 2000 is presented in Table 5 and is also available on www.wheatrust.org.

Table 5. Correspondence between genetic groups and prevalent races of *P. striiformis* sampled from epidemic sites since 2000, Global Rust Reference Center.

Common names for prevalent races and genetic groups in yellow rust - GRRC, February 2019			
Genetic group	**Race**	**Virulence phenotype***	**Prevalence in geographical region**
PstS0	*Brigadier*	1,2,3,-,-,-,-,-,9,-,-,17,-,25,-,-,-,AvS,-	Europe
	Brigadier,v4	1,2,3,4,-,-,-,-,9,-,-,17,-,25,-,-,-,AvS,-	Europe
	Madrigal_Lynx	1,2,3,-,-,6,-,-,9,-,-,17,-,25,-,-,-,AvS,-	Europe
	Madrigal_Lynx,v4	1,2,3,4,-,6,-,-,9,-,-,17,-,25,-,-,-,AvS,-	Europe
	Robigus	1,2,3,4,-,-,-,-,9,-,-,17,-,25,-,32,-,AvS,-	Europe
	Robigus,v7	1,2,3,4,-,-,7,-,9,-,-,17,-,25,-,32,-,AvS,-	Europe
	Solstice_Oakley	1,2,3,4,-,6,-,-,9,-,-,17,-,25,-,32,-,AvS,-	Europe
	Solstice_Oakley,v7	1,2,3,4,-,6,7,-,9,-,-,17,-,25,-,32,-,AvS,-	Europe
	Tulsa	-,-,3,4,-,6,-,-,-,-,-,-,-,25,-,32,-,AvS,-	Europe
	Other	Other	Europe, South America
PstS1	*PstS1*	-,2,-,-,-,6,7,8,9,-,-,-,-,25,-,-,-,AvS,-	North America, Australia
	PstS1,v17	-,2,-,-,-,6,7,8,9,-,-,17,-,25,-,-,-,AvS,-	North America
	PstS1,v10,v24,v27	-,2,-,-,-,6,7,8,9,10,-,-,24,25,27,-,-,AvS,-	East Africa
	Other	Other	North America
PstS2	*PstS2*	-,2,-,-,-,6,7,8,9,-,-,-,-,25,-,-,-,AvS,-	East Africa, West Asia, South Asia
	PstS2,v1	1,2,-,-,-,6,7,8,9,-,-,-,-,25,-,-,-,AvS,-	East Africa, West Asia
	PstS2,v3	-,2,3,-,-,6,7,8,9,-,-,-,-,25,-,-,-,AvS,-	East Africa
	PstS2,v27	-,2,-,-,-,6,7,8,9,-,-,-,-,25,27,-,-,AvS,-	East Africa, West Asia, North Africa
	Pst2,v1,v27	1,2,-,-,-,6,7,8,9,-,-,-,-,25,27,-,-,AvS,-	East Africa, West Asia
	PstS2,v3,v27	-,2,3,-,-,6,7,8,9,-,-,-,-,25,27,-,-,AvS,-	East Africa
	PstS2,v10,v24	-,2,-,-,-,6,7,8,9,10,-,-,24,25,-,-,-,AvS,-	East Africa, West Asia
	PstS2,v3,v10,v24,v27	-,2,3,-,-,6,7,8,9,10,-,-,24,25,27,-,-,AvS,-	East Africa
	PstS2,v10,v24,v27	-,2,-,-,-,6,7,8,9,10,-,-,24,25,27,-,-,AvS,-	West Asia
	Other	Other	East Africa, West Asia
PstS3	*PstS3* *PstS3,v10,v24* *PstS3(-)*	-,-,-,-,-,6,7,8,-,-,-,-,-,-,-,-,-,AvS,- -,-,-,-,-,6,7,8,-,10,-,-,24,-,-,-,-,AvS,- -,-,-,-,-,6,7,8,-,-,-,-,-,-,-,-,-,-,-	North Africa, West Asia West Asia Europe, South Asia
PstS4	*Triticale2006* *Other*	-,2,-,-,-,6,7,8,-,10,-,-,24,-,-,-,-,-,- Other	Europe Europe
PstS5	*PstS5* *PstS5,v17* *Other*	1,2,3,4,-,6,-,-,9,-,-,-,-,25,-,32,-,AvS,Amb 1,2,3,4,-,6,-,-,9,-,-,17,-,25,-,32,-,AvS,Amb Other	Central Asia Central Asia, South Asia Central Asia, South Asia
PstS6	*PstS6*	1,2,-,-,-,6,7,-,9,-,-,17,-,-,27,-,-,AvS,-	East Africa, Central Asia, South Asia
PstS7	*Warrior*	1,2,3,4,-,6,7,-,9,-,-,17,-,25,-,32,Sp,AvS,Amb	Europe
PstS8	*Kranich*	1,2,3,-,-,6,7,8,9,-,-,17,-,25,-,32,-,AvS,Amb	Europe
PstS9	*PstS9* *PstS9,v17* *Other*	1,2,3,4,-,6,-,-,9,-,-,-,-,25,27,32,-,AvS,Amb 1,2,3,4,-,6,-,-,9,-,-,17,-,25,27,32,-,AvS,Amb Other	Central Asia, South Asia Central Asia Central Asia
PstS10	*Warrior(-)*	1,2,3,4,-,6,7,-,9,-,-,17,-,25,-,32,Sp,AvS,-	Europe, North Africa
PstS11	*PstS11*	-,2,-,(4),-,6,7,8,-,-,-,17,-,-,27,32,-,AvS,-	Central Asia, East Africa
PstS12	*Hereford*	-,2,3,-,-,6,7,8,-,-,-,17,-,25,-,32,-,AvS,-	Europe
PstS13	*Triticale2015*	-,2,-,-,-,6,7,8,9,-,-,-,-,-,-,-,-,AvS,-	Europe, South America
PstS14	*PstS14*	-,2,3,-,-,6,7,8,9,-,-,17,-,25,-,32,(Sp),AvS,-	Europe, North Africa

*Figures and symbols designate virulence and avirulence (-) corresponding to yellow rust resistance genes: *Yr1, Yr2, Yr3, Yr4, Yr5, Yr6, Yr7, Yr8, Yr9, Yr10, Yr15, Yr17, Yr24, Yr25, Yr27, Yr32* and the resistance specificity of Spalding Prolific (Sp), Avocet S (AvS) and Ambition (Amb), respectively.

Table 6. People contributing to sampling and submission of rust-infected leaves in 2018.

Country	Collectors 2018
Afghanistan	E. Mohmand, A. Bari Stanikzai, Z. Ahmazada, A. Noori, A. Raqib Lodin, G. Ghanizada, A. Latif Rasekh
Argentina	Agustin Bilbao
	Agustín Pulido
	Alejandro Porfiri
	Ana Rodriguez
	Ana Storm
	Andrea Rosso
	Buck Semillas
	Carina Cáceres
	Carlos Grosso
	Claudio Bosco
	Cristina Palacios
	Diego Alvarez
	Enrique Alberione
	Fabricio Mock
	Franco Petrelli
	Gustavo Duarte
	Ignacio Erreguerena
	Julián Garcia, Oro Verde
	Liliana Wehrhahne, Adelina Larsen
	Manuela Gordo
	Marcos Mitelsky
	Margarita Sillon, Magliano F
	Mauro Montarini
	Norma Formento
	Victoria Gonzales, Daniel Ploper
Austria	Michael Oberforster
	Thomas Massinger
Belgium	F. De Brouwer; J. Pannecoucque
	G. Jacquemin & R. Meza
Bhutan	Dave Hodson, Sangay Tshewang
Chile	C. Jobet and R. Galdames
	Carola Vera; Ricardo Madariaga
	Erik Von Baer
Czech Republic	Alena Hanzalova
	Pavel Kraus
Denmark	Susanne Sindberg
	Ghita Cordsen Nielsen
Egypt	Atef Shahin, Wasief Youssief
Eritrea	Ashmelash Wolday
Ethiopia	Ashenafi
	Bekele Abeyo; Ayele Badebo
	Dave Hodson
	Zerihun T.
France	Emmanuel Heurmez
	Gorichon
	J.P. Maigniel
	Laurent Pageaud
	Marc Leconte
	Mathieu Grare
	S. Barrais; V. Cadot

Country	Sampled by
Germany	Kerstin Flath
Iran	Afshari, F.
Italy	Anna Maria Mastrangelo
	Biagio Randazzo
	Giuseppina Goddi
	Francesca Nocente
	Virgilio Balmas
Kenya	R. Wanyera
Latvia	Líga Feodorova-Fedotova
Morocco	Ezzahiri Brahim
Netherlands	Lubbert van den Brink
Norway	Andrea Ficke
	Chloe Grieu
	Morten Lillemo
Pakistan	Sajid Ali
Poland	Ewelina Piwowarczyk
	Pawel Czembor
Rwanda	Dave Hodson, Innocent Habarurema
Slovakia	Svetlana Slikova
Spain	Dolors Villegas
	Enrique Can
	Ibal Elorza
	Jesús Goñi
	Luis Urquijo
	Neus Pulg; Nieves Apa
Sweden	Alexia von Ehrenheim
	Alf Djurberg
	Anna Berlin
	Anna Gerdtsson
	Anna-Karin Krijger
	Charlotte Norén
	Elisabeth Bölenius
	Erling Christensson
	Eva Mellqvist
	Frans Johnson
	Gunilla Berg
	Johanna Holmblad
	Jonas Törngren
	Julia Dahlqvist; Anna von Heideken
	Karin Andersson
	Kristian Jochnick
	Lars Johansson
	Lina Norrlund
	Lukas Hallberg
	Robert Dinwiddie
Tanzania	Rose Mongi; Dave Hodson; Ari Uyole
Ukraine	Vitaliy Paljasniy
Uzbekistan	Zafar Ziyaev

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A summary of the results can be shared within relevant countries and organisations providing appropriate citation of this report.

XIII Susceptibility of winter wheat cultivars exposed to races of yellow rust in inoculated field trials in Denmark

Mogens Støvring Hovmøller, Julian Rodriguez-Algaba, Mehran Patpour & Chris Khadgi Sørensen

Yellow rust susceptibility in wheat cultivars is highly dependent on virulence patterns of pathogen races. In these trials, the susceptibility to three races of *Puccinia striiformis* which are already established in Denmark was investigated under medium-high disease load during the main growing season. The cultivars investigated had been selected according to their current importance in Denmark and Sweden, taking into account amounts of certified seeds sold and future prospects for their cultivation. The trials are complementing the 'Value for Cultivation and Use' (VCU) trials of new wheat cultivars, where foliar disease is generally present according to natural fluctuations across years and locations and often subject to some level of disease management.

Methods

The cultivars were sown in a seed-matic system, where each 1-m^2 plot consisted of two individual rows per cultivar and two adjacent spreader rows supporting the applied pathogen race (Figure 1). The cultivars were sown in three replications per block. Spreader rows were inoculated by three individual pathogen races at GS 30-31 by rubbing spores from pots of diseased seedlings, which had been raised and inoculated in the lab/greenhouse, one single race per block (Table 1). The blocks were separated by distance and guard plants of winter barley to reduce the amount of cross-contamination of races between blocks. The timing of inoculation was adjusted to ensure optimal and conducive rust infection conditions in the second half of April. The trials were irrigated 2-4 times with 20-25 mm water each time to compensate for lack of rain in May and June 2018.

Table 1. Isolates applied in inoculated nurseries of wheat yellow rust in field trials in 2018.

Genetic group	Race	Virulence phenotype*	Prevalent in
PstS0	Solstice/Oakley	1,2,3,4,-,6,7,-,9,-,-,17,-,25,-,32,-,AvS,-	Europe
PstS10	Kalmar	1,2,3,4,-,6,7,-,9,-,-,17,-,25,-,32,Sp,AvS,-, Kal	Europe
PstS14	PstS14	-,2,3,-,-,6,7,8,9,-,-,17,-,25,-,32,Sp,AvS,-	Europe, North Africa

* Figures and symbols designate virulence and avirulence (-) corresponding to yellow rust resistance genes: Yr1, Yr2, Yr3, Yr4, Yr5, Yr6, Yr7, Yr8, Yr9, Yr10, Yr15, Yr17, Yr24, Yr25, Yr27, Yr32, and the resistance specificity of Spalding Prolific (Sp), Avocet S (AvS), Ambition (Amb) and Kalmar (Kal), respectively.

Twenty-nine wheat cultivars from Sweden, submitted via an ongoing collaboration with Jordbruksverket, and twenty-one cultivars from Denmark were investigated in two field trials in addition to three yellow rust susceptible checks. Diseases were scored at GS 51, GS 65 and GS 71, respectively, using a %-scale where the midpoint of the scale equals 5%, i.e. the same scale as recommended by UPOV (Anon., 2017) (Table 2).

Table 2. Assessment scale for foliar disease in wheat translated into the 1-9 scale recommended by UPOV. In the present case, midpoint % values were occasionally applied, e.g. 3% as midpoint between 1% and 5% and 7.5% as midpoint between 5% and 10%.

Disease severity (%)	UPOV[a] equivalent	Symptoms at crop/plot level (descriptions indicative)			
		Leaf rust	Yellow rust	Powdery mildew	Septoria / tan spot
0	1	No attack			
0.1 (trace)	2	Few postules per plant	Few stripes per plant (foci)	Few colonies per plant	Max one spot per plant
0.5	3	Few postules per plant	Few stripes per tiller	Few colonies per tiller	Max one spot per tiller
1	4	Several postules per tiller on lower leaves	Several lesions/stripes per tiller (lower leaves)	Several colonies per tiller (lower leaves)	Few spots per plant (lower leaves)
5	5	Lower leaves up to 10-25% coverage	Leaves with overlapping lesions	Lower leaves up to 10-25% coverage	Lower leaves up to 10-25% coverage
10	6	Lower leaves typically 25% coverage or more			
25	7	Lower leaves 50% coverage or more			
50	8	Half of leaves senescent, lower leaves 75-100% coverage			
>75	9	Almost no green leaf area left			

[a](Anon., 2017).

Figure 1. Field trial layout with spreader rows inoculated with single races of yellow rust.

Results and conclusions

Yellow rust was well established on spreader rows in both trials and for all races with visible symptoms at the beginning of May. Tables 3 and 4 present the average disease scores (in %) based on assessment of the top 3-4 leaves. Despite the lack of rain, the high quality inoculum, natural dew formation during the night and irrigation in May and June ensured a sufficient disease load ranging approximately from 5 to 25% on the susceptible controls Anja, Oakley and Substance. This allowed a nice differentiation of yellow rust susceptibility as shown in Table 3 and Table 4.

Table 3. Yellow rust severity (%) for 29 wheat cultivars from Sweden after inoculation using three *P. striiformis* races (Table 1). Assessments were based on the 3-4 top leaves and the results represent averages across three replications per assessment date.

Cultivar	Kalmar race		Oakley race		PstS14 race	
	29.05.2018	16.06.2018	29.05.2018	16.06.2018	29.05.2018	16.06.2018
Anja	7.5	7.5	4.3	4.3	21.3	21.3
Oakley	25.0	25.0	12.5	17.5	25.0	25.0
Substance	9.2	9.2	8.3	9.2	11.7	11.2
Brons	0.0	0.0	0.0	0.0	0.0	0.0
Ceylon	0.0	0.0	0.0	0.0	0.0	0.0
Ellen	0.0	0.1	0.0	0.0	0.0	0.0
Ellvis	4.3	5.2	0.0	0.3	0.0	0.0
Etana	0.0	0.0	0.0	0.0	0.0	0.0
Festival	0.0	0.0	0.0	0.0	0.0	0.0
Hacksta (SW15423)	1.4	2.3	0.0	0.3	0.0	0.0
Hallfreda (SW15646)	0.0	0.0	0.0	0.0	0.0	0.0
Hellas (SW 15541)	0.0	0.0	0.0	0.0	0.0	0.0
Imposanto	0.0	0.0	0.0	0.0	0.0	0.0
Inese (SW 15394)	0.0	0.0	0.0	0.0	0.0	0.0
Informer	0.0	0.0	0.5	2.3	0.0	0.0
Julius	8.3	8.3	0.0	1.7	0.5	0.7
KWS Ahoi	3.3	4.2	0.0	2.0	0.1	0.1
KWS Kerrin	1.0	1.0	0.0	0.0	0.0	0.0
KWS Talent	0.0	0.0	0.0	0.0	0.0	0.0
Linus	0.0	0.0	0.8	0.8	0.0	0.0
Mariboss	0.0	0.0	0.0	0.0	0.0	0.0
Memory	0.1	0.1	0.0	1.0	1.8	1.8
Nordh	0.0	0.0	0.1	1.3	0.0	0.0
Norin	0.0	0.0	0.0	0.0	0.7	0.7
Praktik	0.0	0.0	0.2	0.2	0.0	0.0
RGT Reform	0.0	0.0	0.7	0.7	0.0	0.0
RGT Treffer	0.0	0.0	0.2	0.2	0.0	0.0
Rockefeller	0.0	0.0	0.2	0.2	0.0	0.0
SJ L632	0.0	0.0	1.7	4.3	0.0	0.0
Stava	0.2	0.4	0.0	0.0	0.0	0.0
Stinger	0.0	0.0	1.5	2.8	0.3	0.3
Torp	0.3	0.3	5.2	7.5	0.0	0.0
Grand total	**1.9**	**2.0**	**1.1**	**1.8**	**1.9**	**1.9**

Table 4. Yellow rust severity (%) on 21 wheat cultivars from Denmark after inoculation using three *P. striiformis* races (Table 1). Assessments were based on the 3-4 top leaves and the results represent averages across three replications per assessment date.

Cultivar	Kalmar race		Oakley race		PstS14 race	
	28.05.2018	15.06.2019	28.05.2018	15.06.2019	28.05.2018	15.06.2019
Anja	10.0	10.0	5.8	5.8	22.5	22.5
Oakley	22.5	25.0	7.5	11.7	25.0	25.0
Substance	20.0	25.0	15.0	15.0	22.5	22.5
Benchmark	0.0	0.0	0.0	0.4	0.0	1.0
Canon	7.5	7.5	4.5	2.0	0.0	0.0
Creator	1.7	1.7	2.3	3.7	2.3	2.3
Elixer	1.7	3.0	0.4	1.0	0.0	0.0
Empero	0.0	0.0	0.0	0.0	0.1	0.1
Graham	0.0	0.0	0.0	0.0	0.0	0.0
Hereford	0.2	0.2	0.0	0.0	0.0	0.0
Kaldi	0.0	0.0	0.0	0.0	0.0	0.0
Kalmar	20.0	20.0	0.2	3.5	0.0	1.7
KWS Cleveland	0.0	0.0	0.4	0.7	0.1	0.1
KWS Dacanto	0.0	0.0	0.5	0.8	0.0	0.0
KWS Lili	0.2	0.5	0.2	0.2	6.7	7.5
KWS Nils	0.0	0.0	0.8	6.0	0.0	0.0
KWS Zyatt	0.0	0.0	0.0	0.1	0.4	0.8
Nuffield	0.2	0.2	5.8	7.5	0.0	0.0
Ohio	0.0	0.0	0.1	0.1	0.0	0.0
Pistoria	0.0	0.0	0.0	0.0	0.0	0.0
RGT Universe	0.0	0.0	0.0	0.0	0.0	0.0
Sheriff	1.4	1.4	0.2	0.2	0.2	0.2
Torp	0.1	0.4	3.0	4.3	0.0	0.0
Viborg	7.5	10.0	0.0	0.3	0.0	0.0
Grand total	**3.0**	**3.5**	**1.5**	**2.0**	**2.6**	**2.8**

The results highlighted a number of significant race-specific interactions between the three races and the cultivars, highlighting the importance of testing wheat cultivars and breeding lines to prevalent (and upcoming) races of *P. striiformis* as basis for IPM recommendations to both conventional and organic farmers. The high level of resistance in more than half of the investigated cultivars stresses that valuable sources of resistance to the yellow rust fungus are already present in well-adapted wheat cultivars in Scandinavia. However, some of the cultivars may show susceptibility to races which were not included in the 2018 trials. The Solstice/Oakley race was prevalent in Europe between 2006 and 2009 (Hovmøller et al., 2016), whereas the PstS14 was first detected in Europe in 2015/2016, highlighting the fact that "old" races like Solstice/Oakley may reveal higher levels of 'susceptibility' than recent races. Updated information about prevalence of *P. striiformis* races in Europe as well as globally is available at the web-site of the Global Rust Reference Center (www.wheatrust.org).

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XIV List of chemicals

Fungicides		
Name	**Active ingredients**	**Gram /L or kg**
Adexar Extra	Epoxiconazole + fluxapyroxad	62.5 + 62.5
Aliette	Fosethyl-al	800
Amistar	Azoxystrobin	250
Armure	Difenoconazole + propiconazole	150 + 150
Ascar Xpro	Prothioconazole + bixafen + fluopyram	130 + 65 + 65
Aviator Xpro	Bixafen + prothioconazole	75 + 160
BAS 751 00 F	Mefentrifluconazole + pyraclostrobin	100 + 100
BAS 752 03 F	Mefentrifluconazole + fluxapyroxad	66.7 + 66.7
Bell	Boscalid + epoxiconazole	233 + 67
Bravo 500 SC	Chlorothalonil	500
Bumper 25 EC	Propiconazole	250
Caramba 60	Metconazole	60
Comet granulate	Pyraclostrobin	200
Comet Pro (Comet 200)	Pyraclostrobin	200
Curzate M68 WG	Mancozeb + cymoxanil	680 + 45.2
Cymbal 45	Cymoxanil	450
Dithane NT	Mancozeb	750
Elatus Era	Azoxystrobin + benzovindiflupyr	30 + 15
Flexity	Metrafenon	300
Folicur EW 250	Tebuconazole	250
Folpan 500 SC	Folpet	500
GF-3307	Prothioconazole + fenpicoxamid	100 + 50
GF-3308	Fenpicoxamid	50
Imtrex	Fluxapyroxad	62.5
Input EC 460	Prothioconazole + spiroxamine	160 + 300
Juventus 90	Metconazole	90
Kumulus S	Sulphur	800
Librax	Fluxapyroxad + metconazole	62.5 + 45
Narita	Difenoconazole	250
Opera	Pyraclostrobin + epoxiconazole	133 + 50
Opus	Epoxiconazole	125
Opus Max	Epoxiconazole	83
Priaxor	Pyraclostrobin + pyraclostrobin	150 + 75
Proline EC 250	Prothioconazole	250
Proline Xpert	Tebuconazole + prothioconazole	80 + 160
Propulse SE 250	Fluopyram + prothioconazole	125 + 125
Prosaro EC 250	Prothioconazole + tebuconazole	125 + 125
Proxanil	Propamocarb + cymoxanil	333.6 + 50
Quilt Xcel	Azoxystrobin + propiconazole	135 + 117
Ranman Top	Cyazofamid	160

Fungicides		
Name	**Active ingredients**	**Gram /L or kg**
Revus	Mandipropamid	250
Revus Top	Mandipropamid + difenoconazole	250 + 250
Rubric	Epoxiconazole	125
Score 250 EC	Difenoconazole	250
Serenade ASO	Bacillus subtilis	1000
Signum WG	Pyraclostrobin + boscalid	67 + 267
Siltra Xpro	Bixafen + prothioconazole	60 + 200
Talius	Proquinazid	200
Tilt 250 EC	Propiconazole	250
Vendetta	Fluazinam + azoxystrobin	375 + 150
Viverda	Epoxiconazole + pyraclostrobin + boscalid	50 + 60 + 140
Zorvec Enicade	Oxathiapiprolin	100

Herbicides		
Name	**Active ingredients**	**Gram /L or kg**
Atlantis OD	Mefenpyr + mesosulfuron + iodosulfuron	30 + 10 + 2
Broadway	Pyroxsulam + florasulam	68.3 + 22.8
Cossack OD	Iodosulfuron + mesosulfuron	7.5 + 7.5
Glyphomax	Glyphosate	360
Glypper	Glyphosate	360
Roundup Flex	Glyphosate	480
Roundup PowerMax	Glyphosate	720

Growth regulators		
Name	**Active ingredients**	**Gram /L or kg**
Cerone	Ethephon	480
Medax Top	Mepiquat-chlorid + prohexadion-calcium	300 + 50
Moddus M	Trinexapac-ethyl	250
Stabilan Extra	Chlormequat-chlorid	750
Trimaxx	Trinexapac-ethyl	175

DCA - National Centre for Food and Agriculture is the entrance to research in food and agriculture at Aarhus University (AU). The main tasks of the centre are knowledge exchange, advisory service and interaction with authorities, organisations and businesses.

The centre coordinates knowledge exchange and advice with regard to the departments that are heavily involved in food and agricultural science. They are:

Department of Animal Science
Department of Food Science
Department of Agroecology
Department of Engineering
Department of Molecular Biology and Genetics

DCA can also involve other units at AU that carry out research in the relevant areas.

SUMMARY

This publication contains results from crop protection trials which were carried out at the Department of Agroecology within the area of agricultural crops. Most of the results come from field trials, but results from greenhouse and semi-field trials are also included. The report contains results that throw light upon:

- Effects of new pesticides
- Results of different control strategies, including how to control specific pests, as part of an integrated control strategy involving both cultivars and control thresholds
- Results with pesticide resistance
- Trial results from different cropping systems
- Annual report from the Global Rust Reference Center

APPLIED CROP PROTECTION 2018

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