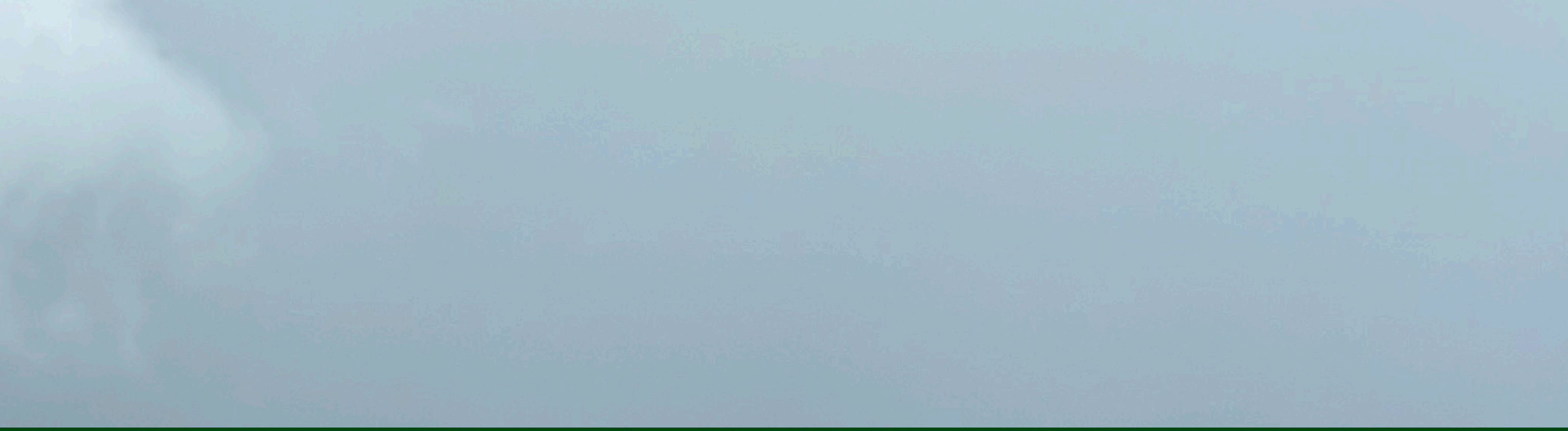

APPLIED CROP PROTECTION 2024

BRITTANY DEANNA BECK, LISE NISTRUP JØRGENSEN, NIELS MATZEN, ISAAC KWESI ABULEY, PETER KRYGER JENSEN & SOFIE ROSENGAARD NØRHOLM

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Preface

The publication "Applied Crop Protection" is an annual report providing results and advice on crop protection to farmers, advisors, industry and researchers. The publication summarises data which are regarded to be of relevance for practical farming and advice. It covers information on the efficacy profiles of new pesticides and biologicals, effects of implementation of IPM (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 pesticide resistance to ensure that only effective strategies are used by the farmers to minimise build-up of resistance.

The series of reports was initiated in 1991 when the 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 the EU's legislation for efficacy data. Efficacy testing of pesticides was opened up to all trial units which had obtained a GEP certification (Good Experimental 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 greater outreach.

The choice of topics, the writing and the publishing of the report are done entirely by staff at AU, and the report contents are not shared with the industry before publication. All authors and co-authors are from AU, and no part is written or commented on by external partners. The data on which the writing is based are 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 supplied pesticides and advice on their use for the trials, and plant breeders provided the cultivars included in specific trials. Trials were located either at AU's research stations or in fields owned by private trial hosts. AU collaborated with local advisory centres and SEGES on several of the projects, e.g. when assistance was needed regarding sampling for resistance or when looking for specific sites with specific targets. Several of the results were also published in shared newsletters with SEGES to ensure a fast and direct communication to farmers.

Internal scientific review of specific chapters was carried out by AU AGRO colleagues Brittany Deanna Beck (overall editing), Peter Kryger Jensen (Chapters II and III), Lise Nistrup Jørgensen (Chapter VII), Mette Sønderskov (Chapter IV), Annemarie Fejer Justesen (Chapter V), Birte Boelt (Chapter VIII) and Mogens Støvring Hovmøller (Chapter VI).

List of funding

Chapter I: Climate data for the growing season 2023/2024. The information was adjusted by AU based on information from DMI.

Chapter II: Disease control in wheat. Trials in this chapter were financed by ADAMA, BASF, Bayer Crop Science, Corteva Agriscience, Syngenta and UPL, but certain elements were also based on AU's own funding.

Chapter III: Disease control in barley. Trials in this chapter were financed by BASF, Bayer Crop Science and Syngenta, but certain elements were also based on AU's own funding.

Chapter IV: Control strategies in different cereal cultivars. Trials in this chapter were financed by income from selling the DSS system Crop Protection Online, by the Danish Environmental Protection Agency's Pesticide Research Programme (Grant no. 2021-68771), by the EU project Adopt-IPM (Grant Agreement no. 101060430) and by Bayer Crop Science supporting the qPCR activity. Certain elements were based on AU's own funding.

Chapter V: Fungicide resistance-related investigations. Testing for fungicide resistance was carried out based on a shared cost covered by projects and the industry. In 2024 ADAMA, BASF, Bayer Crop Science and Syngenta were involved from the industry. The Swedish part was financed by the Swedish Board of Agriculture; elements were based on AU's own funding.

Chapter VI: Impact of cultivar mixtures on Fusarium head blight in winter wheat. This testing was part of a project financed by the Danish Environmental Protection Agency's Pesticide Research Programme and by the EU project Adopt-IPM.

Chapter VII: Fungicide anti-resistance strategies in managing potato late blight. The work was funded by the Danish Environmental Protection Agency's Pesticide Research Programme (Grant no. 2022-89507).

Chapter VIII: The fate of rattail fescue (*Vulpia myuros* L.) emerging in the spring: Investigation of differences in vernalisation requirements. The investigation was financed by the Danish Seed Levy Fund (Frøafgifts-fonden).

Chapter IX: List of chemicals.

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I Climate data for the growing season 2023/2024

Sofie Rosengaard Nørholm

The first section of this chapter evaluates the overall weather conditions in Denmark during the growing season and the second section is data recorded at the AU Flakkebjerg weather station where most of Aarhus University trials were located (September 2023 – August 2024).

Denmark:
The autumn in Denmark 2023 was warm with above average levels of precipitation (299.4 mm). There was an increase of 64.9 mm of precipitation to the past 10-year average (2011-2020). The wettest November since 1874 occurred with precipitation of 96.8 mm, while September at 16.3°C was the warmest since 1874. The average autumn temperature was 10.3°C, only a slight increase of 0.2°C to the 10-year average (2011-2020).

The 2023/2024 winter had 286.3 mm of rainfall and was the second wettest winter since 1874. This was 92.2 mm more rainfall than the past 10-year average (2011-2020). The winter temperature of 2.7°C was only 0.4°C higher than the 10-year average (2011-2020).

The 2024 spring in Denmark was wet with 197.7 mm of precipitation, which was 50% more than the 30-year average (1991-2020). During this period, April was the wettest month with 104 mm of rainfall and the spring temperature was the warmest since 1874. The average temperature was 9.1°C, which was 1.8°C above the normal temperature (1991-2020).

The summer of 2024 was very wet with 295.6 mm of precipitation, 39% above the normal precipitation levels (1991-2020). This was the summer with the sixth highest amount of precipitation since 1874. The temperature during the summer was average (compared to 1991-2020).

Flakkebjerg:
At AU Flakkebjerg, the precipitation in the autumn 2023 was 248.6 mm, which was 51% higher than the recorded average in the period 2011-2023. September was a dry month, but October and November had a lot of precipitation. The temperature in the autumn was on average 10.7°C at AU Flakkebjerg (average 10.3°C for the period 2011-2023).

During the winter, the precipitation was 267.9 mm, which was 75% higher than average at AU Flakkebjerg (2011-2023). Specifically, February had 210% higher levels of precipitation than the February average (2011-2023). The 2023/2024 winter temperature was close to the average temperature of 3.0°C (3.4°C on average for 2011-2023).

The average spring temperature of 9.3°C at AU Flakkebjerg was a 1.7°C increase to the average spring temperature (2011-2023). The spring precipitation was 187.7 mm, which was 10.0 mm less than the average national spring precipitation. March was very dry with only 26.7 mm of rain.

With a total rainfall of 178.9 mm, there was a 17% rainfall increase in the summer to the average of 2011-2023. The national precipitation was 116.7 mm more precipitation than at AU Flakkebjerg. The temperature was 16.6°C, approximately the average temperature at AU Flakkebjerg (2011-2023).

Overall, the very wet months from April to July influenced the disease pressure, giving the fungi good conditions for spreading, and therefore irrigation was neither needed nor used.

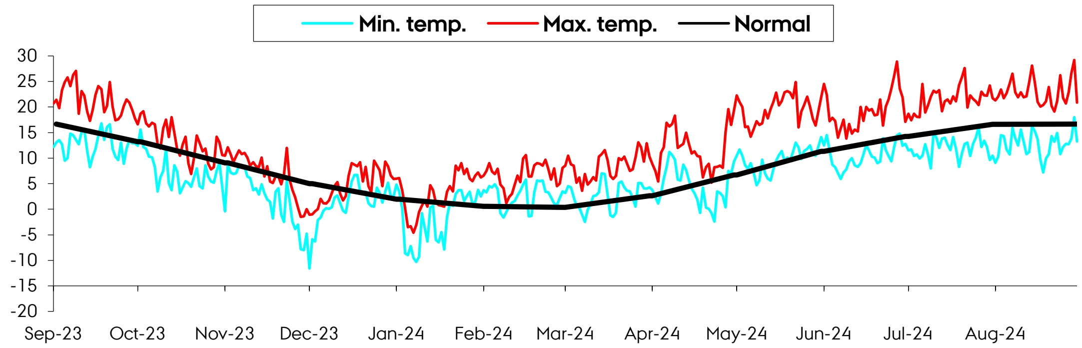


Figure 1. Climate data graph from AU Flakkebjerg for the growing season September 2023 – August 2024. The temperature is in °C.

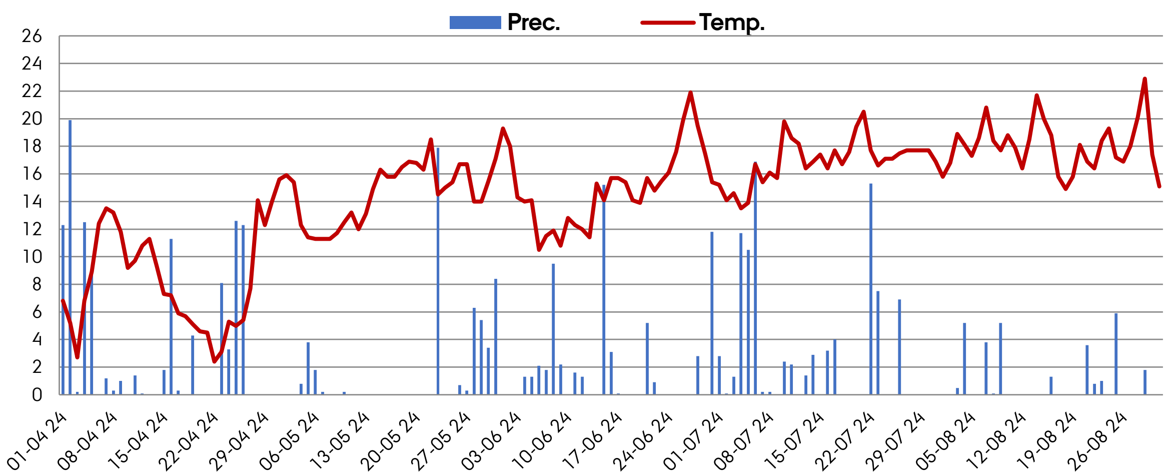


Figure 2. Climate data graph from AU Flakkebjerg for spring and summer 2024. The temperature is in °C and the precipitation is in mm.

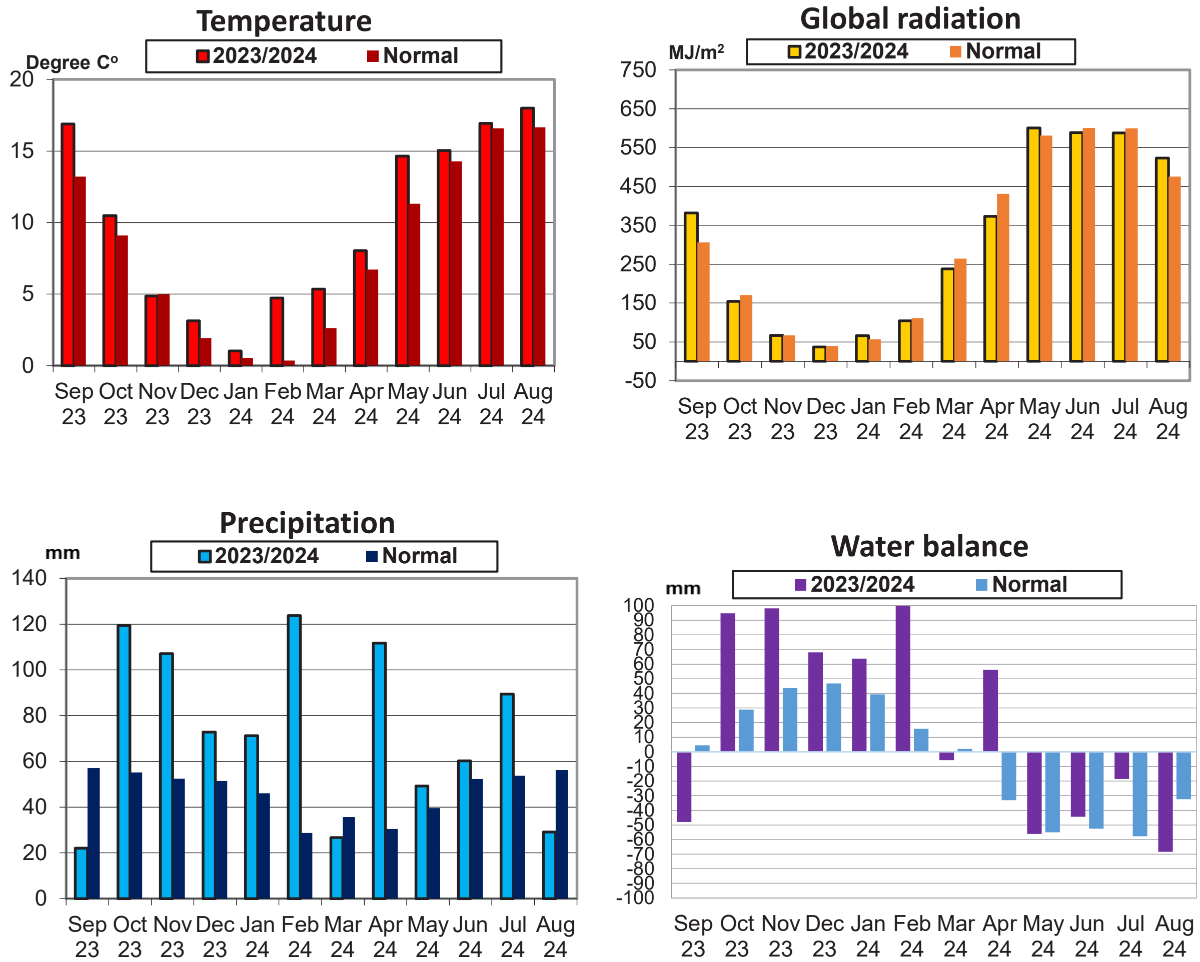
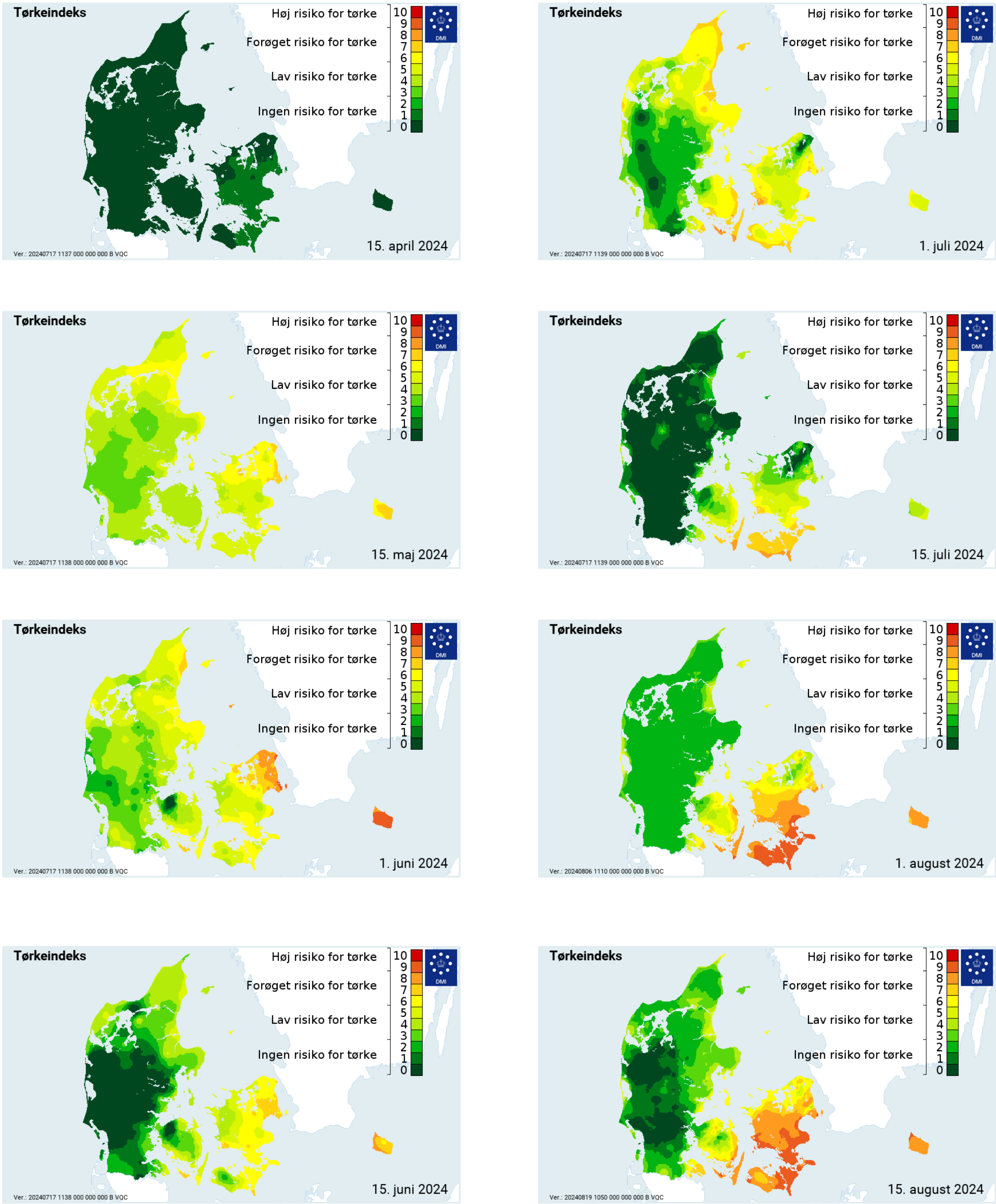


Figure 3. Climate data from AU Flakkebjerg for the growing season September 2023 – August 2024. The temperature is in °C, the global radiation is measured in MJ/m^2, the precipitation is in mm, and the water balance is the difference between precipitation and potential evaporation.



Drought index 2024 (DMI)

- 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 4. Drought index for March-August 2024. Danish Meteorological Institute (DMI).

II Disease control in wheat

Brittany Deanna Beck, Niels Matzen, Hans-Peter Madsen, Christian Appel Schjeldahl Nielsen, Sofie Rosengaard Nørholm, Anders Almskou-Dahlgaard & Lise Nistrup Jørgensen

Introduction

In this chapter, the 2024 fungicide field trials in wheat are described in brief, and results are summarised. Trial plans that cover several years may have graphs or tables from previous years included to summarise the whole project. The trials are testing new fungicides as well as timings and dose rates of products, and the main results on the major diseases are presented. The trial results are sometimes used as a part of the Biological Assessment Dossier, which companies must prepare to obtain authorisation for new products or for re-evaluations of old products. Another aim of the trials is to solve questions related to optimising the use of fungicides in common control situations for specific diseases. The chapter shows data in tables and figures, and comments and concluding remarks are given on the trials. Most data summarised in this chapter are funded by the companies ADAMA, BASF, Bayer Crop Science, Corteva Agriscience, Syngenta and UPL, who pay to have their products tested. Data are also presented from the activity organised under the umbrella of EuroWheat, financed by BASF. EuroWheat is organised by Aarhus University (AU) in collaboration with different organisations that run trials in other countries. All the data from the project are analysed by AU, who also publishes the data. In several trial plans, individual treatments are included based on AU's own initiative.

Methods

All field trials with fungicides are carried out as GEP trials. The majority of the trials are carried out on fields at AU Flakkebjerg. Some of the trials are also located in farmers' fields, at Jyndevad Experimental Station or near Horsens in collaboration with a GEP trial unit at the advisory group Velas. Trials are carried out as block trials with randomised plots and four replicates. Plot sizes vary from 14 m^2 to 35 m^2, depending on the individual unit's equipment. The trials are placed in fields with moderately to highly susceptible cultivars, specifically chosen to increase the chances of disease development. Spraying is carried out using a self-propelled sprayer and a water volume of 150 litres or 200 litres per hectare.

Disease assessments in the trials are done at approximately 10-day intervals during the season. Per cent leaf area attacked by each individual disease is assessed on specific leaf layers in accordance with EPPO guideline 1/26 (4), 'Foliar and ear diseases on 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 two upper leaves. In this publication, only some assessments are included – mainly the ones giving the best differentiation of the efficacy of the products. Significant diffence in tables is based on ANOVA analysis in ARM (Agricultural Research Manager) shown using least significant differences at 5% level ($P \leq 0.05$) written as LSD_{95}.

Nearly all trials are carried through to harvest, and yield is adjusted to 15% moisture content. Quality parameters like specific weight (kg/hl), % protein, % starch and % gluten content are measured, using NIT instruments (Foss, Perten), and thousand grain weight (TGW) 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 multiple comparisons are included with specific letters signifying significant differences. When a net yield is calculated, it is converted to dt/ha based on deducting the cost of chemicals used and the cost of application. The cost of application (cost in dt/ha = cost of treatment DKK/ha / grain price DKK/dt) has been set at DKK 70 and the cost of chemicals was extracted from the database at SEGES. The grain price used is DKK 165 per dt wheat and DKK 160 per dt barley.

EuroWheat – comparing effects of SDHIs

This trial was part of the EuroWheat activity in which 10 trials were carried out across different European countries. The focus of the trials was to investigate the efficacy of SDHIs (succinate dehydrogenase inhibitors) in regions with different climates and levels of resistance. The tested products are shown in Table 1. One trial was conducted at AU Flakkebjerg in the cultivar LG Skyscraper and was treated at Growth Stage (GS) 37-39 (15 May) to protect the flag leaf. The trial only developed a moderate infection of Septoria tritici blotch as shown in Table 2. The Danish trial showed a high level of control from most of the test products, including both solo SDHI and solo mefentrifluconazole. The product Proline EC 250 gave only a low to moderate level of control similar to control levels seen in previous years. In the project, overall mutation in the *Septoria* populations was assessed, and the results can be found in the chapter on resistance (Chapter V). In Denmark, all treatments except for Proline EC 250 gave a significant yield increase.

Table 1. Protocol for products tested similarly in 10 EuroWheat trials in 2024. DMI = Demethylation Inhibitor, SDHI = Succinate Dehydrogenase Inhibitors, QiI = Quinone inside Inhibitors.

Treatments GS 37-39	Active ingredient	Active group	BAS No.	Dose, l/ha	g a.i./ha	Std. dose %
1. Untreated control	-	-	-	-	-	-
2. Revysol	Mefentrifluconazole	DMI	BAS75001F	1.0	100	67
3. Revysol	Mefentrifluconazole	DMI	BAS75001F	1.5	150	100
4. Proline EC 250	Prothioconazole	DMI	BAS93141F	0.8	200	100
5. Questar	Fenpicoxamid	QiI	BAS97000F	2.0/1.5*	100/75	100
6. Revystar XL	Fluxapyroxad + mefentrifluconazole	SDHI + DMI	BAS75200F	1.5	150 + 75	100
7. Revytrex	Fluxapyroxad + mefentrifluconazole	SDHI + DMI	BAS75203F	1.5	100 + 100	100
8. Elatus Era	Benzovindiflupyr + prothioconazole	SDHI + DMI	BAS95780F	1.0	75 + 150	100
9. Ascra Xpro	Bixafen + fluopyram + prothioconazole	SDHI + SDHI + DMI	BAS97700F	1.5	98 + 98 + 195	100
10. Imtrex	Fluxapyroxad	SDHI	BAS70009F	2.0	125	100
11. Thore	Bixafen	SDHI	BAS94990F	1.0	125	100
12. Elatus Plus	Benzovindiflupyr	SDHI	BAS95660F	0.75	75	100

*1.5 l/ha in Belgium and France.

Table 2. Effect of applications on control of *Septoria* and brown rust in wheat, using a QiI (quinone inside inhibitor), SDHIs, azoles and co-formulations of the two groups. Treatments were applied at GS 37-39. Green leaf area (GLA) and yield responses. One trial (24328). Data from the Danish trial in EuroWheat. The disease severity is shown for untreated.

Treatments, l/ha		% *Septoria*				% brown rust	% GLA	Yield (untr.) & yield increase, dt/ha
GS 37-39	Dose	GS 70 Leaf 2	GS 70 Leaf 3	GS 75 Leaf 2	GS 77 Leaf 1	GS 77 Leaf 1	GS 77 Leaf 2	
1. Untreated		12.8	36.8	57.5	19.0	1.8	7.5	91.50
2. Revysol	1.0	1.8	6.5	15.0	8.3	1.0	60.0	12.93
3. Revysol	1.5	1.1	5.3	8.0	5.8	1.1	61.3	10.80
4. Proline EC 250	0.8	7.3	18.6	27.5	14.8	1.1	20.0	2.02
5. Questar	2.0	0.6	3.8	4.3	4.8	0.8	67.5	10.39
6. Revystar XL	1.5	0.5	3.4	4.0	5.0	1.0	68.8	12.56
7. Revytrex	1.5	0.8	4.6	4.5	5.5	1.5	70.0	13.99
8. Elatus Era	1.0	2.6	8.5	13.8	5.5	0.5	53.8	10.98
9. Ascra Xpro	1.5	0.8	4.9	6.0	5.5	1.5	63.8	12.06
10. Imtrex	2.0	1.8	7.5	13.3	5.5	0.9	57.5	14.70
11. Thore	1.0	6.3	16.9	22.5	14.5	0.5	30.0	6.67
12. Elatus Plus	0.75	5.5	15.7	28.8	9.8	0.4	26.3	9.46
LSD_{95}		2.09	5.97	7.01	2.70	0.79	15.55	5.11

The other countries followed the same protocol as the Danish trial, and the efficacy of the different chemicals depended greatly on the location of the experiment. The results of the 10 trials carried out in Denmark, the UK, Ireland, France, Germany, Poland and Belgium are shown for the different fungicides in Table 3, assessed on the flag leaf and the 2nd leaf. In the different countries, a moderate to severe development of *Septoria* was seen. *Septoria* was assessed on the flag leaf in 8 trials and on the 2nd leaf also in 8 trials. Overall, the efficacy of the co-formulations Revytrex and Revystar XL performed best for control of *Septoria* along with fenpicoxamid (Questar).

The levels of *Septoria* attack were high in many trials, which challenged the control effects. Only one trial in Germany (JKI) showed no *Septoria* attack. On average, effects were lower for most treatments in comparison with results from previous years due to high disease pressure and more curative timings (Table 3). This reduced efficacy was most pronounced for the most effective treatments. Fungicide effects were on average generally lower for all products in Belgium and the UK than in the other trials. High effects on the two top leaves were obtained from most products in Denmark. The most effective products were Questar, Revystar XL and Revytrex with an average of 66-71% on leaf 1. Overall, moderate effects were seen from Revysol, Elatus Era, Ascra Xpro and Imtrex with an average of 58-63%. Proline 250 EC, Thore and Elatus Plus stood out with clearly inferior effects of 36-43% on average on leaf 1. The summarised data are shown in Figure 1. Similar patterns of effects were seen on leaf 2, but the effect levels were lower and differences between treatments much less pronounced.

In four trials, brown rust developed moderate to severe attacks (the UK and Germany). The products Questar, Thore and Proline EC 250 had a lower efficacy on brown rust compared with other tested solutions. The summarised data are shown in Figure 2. In one UK trial, solo Elatus Plus (benzovindiflupyr) performed inferiorly to other products, most likely due to development of SDHI fungicide resistance, which is reported to have developed in certain areas.

Overall, the pattern of yield increases mostly fits that of the control effects with some of the highest increases provided by Questar (16.2 dt/ha), Revystar XL (15.5 dt/ha) and Revytrex (13.8 dt/ha). The lowest yield responses were measured following the use of Proline EC 250 (6.6 dt/ha) and Thore (5.3 dt/ha). The summarised yield data are shown in Figure 3.

Table 3. Per cent control of *Septoria* at GS 65-77, 20-42 days after application (DAA), on the flag leaf and the 2nd leaf in 2024. Control effects are summarised as percentage reduction of attack relative to untreated plots. Colours signify ranking of treatment effects within trials. Green: highest rated effect. Yellow: medium rated effect. Orange: lowest rated effect. Red: untreated. Severity is presented in untreated. Product dosages are presented in l/ha. For more treatment details, see Table 1.

Control (%), SEPTTR, leaf 1, 2024				Untr.	Revysol		Proline EC 250	Questar	Revystar XL	Revytrex	Elatus Era	Ascra Xpro	Imtrex	Thore	Elatus Plus
				-	1	1.5	0.8	2	1.5	1.5	1	1.5	2	1	0.75
				-	MEF		PTH	FEN	FLX+MEF	FLX+MEF	BENZ+PTH	BIX+FLU+PTH	FLX	BIX	BENZ
Trial	Country	GS	DAA	-	100	150	200	100	150+75	100+100	75+150	98+98+195	125	125	75
24328-1	DK	75	40	6.0	70	78	53	85	92	92	83	92	77	58	62
24328-3	UK, ADAS	65	31	4.9	43	20	12	51	61	49	10	39	55	22	33
24328-4	IE	75	42	52.5	68	70	60	73	69	64	59	71	51	55	58
24328-5	FR	77	23	67.8	61	62	51	69	71	81	57	67	69	46	39
24328-6	DE, LfL	69	31	20.6	82	85	59	86	88	90	73	80	71	63	52
24328-8	PL	75-77	36	24.3	60	70	63	69	87	94	96	86	96	73	89
24328-9	BE	-	20	16.2	53	46	0	64	53	70	31	68	66	0	16
24328-10	DE, LKSH	75	33	64.6	57	68	24	92	73	73	49	59	49	30	50
Avg. DK, FR, DE, PL and BE				33.2	63.8	68.2	41.7	77.3	77.3	83.2	64.9	75.4	71.4	45.1	51.4
Avg. UK and IE				28.7	55.3	45.3	36.2	62.1	65.1	56.6	34.5	54.8	53.2	38.9	45.2
Avg. all trials				32.1	61.7	62.5	40.3	73.5	74.3	76.5	57.3	70.2	66.9	43.5	49.8

Control (%), SEPTTR, leaf 2, 2024				Untr.	Revysol		Proline EC 250	Questar	Revystar XL	Revytrex	Elatus Era	Ascra Xpro	Imtrex	Thore	Elatus Plus
				-	1	1.5	0.8	2	1.5	1.5	1	1.5	2	1	0.75
				-	MEF		PTH	FEN	FLX+MEF	FLX+MEF	BENZ+PTH	BIX+FLU+PTH	FLX	BIX	BENZ
Trial	Country	GS	DAA	-	100	150	200	100	150+75	100+100	75+150	98+98+195	125	125	75
24328-1	DK	75	40	57.5	74	86	52	93	93	92	76	90	77	61	50
24328-3	UK, ADAS	65	31	41.6	56	52	37	73	68	62	37	54	49	26	29
24328-4	IE	75	42	88.9	18	18	15	24	27	8	9	19	9	5	5
24328-5	FR	69	12	86.8	25	28	21	25	36	38	35	37	31	12	7
24328-6	DE, LfL	69	22	8.5	47	65	16	65	61	60	54	62	25	28	24
24328-8	PL	73	31	18.4	53	55	59	62	69	79	84	74	89	65	72
24328-9	BE	-	20	47.2	13	0	0	22	6	4	0	0	25	0	0
24328-10	DE, LKSH	75	33	22.1	42	52	39	74	56	59	38	49	33	22	36
Avg. control (%) in DK, FR, DE, PL, BE				40.1	54.1	64.4	41.5	73.3	69.8	72.7	62.9	68.4	56.0	43.8	45.7
Avg. control (%) in UK and IE				65.3	37.2	34.7	26.1	48.5	47.6	35.1	23.3	36.9	28.8	15.8	17.0
Avg. control (%) all trials				46.4	48.5	54.5	36.4	65.0	62.4	60.1	49.7	57.9	46.9	34.5	36.1

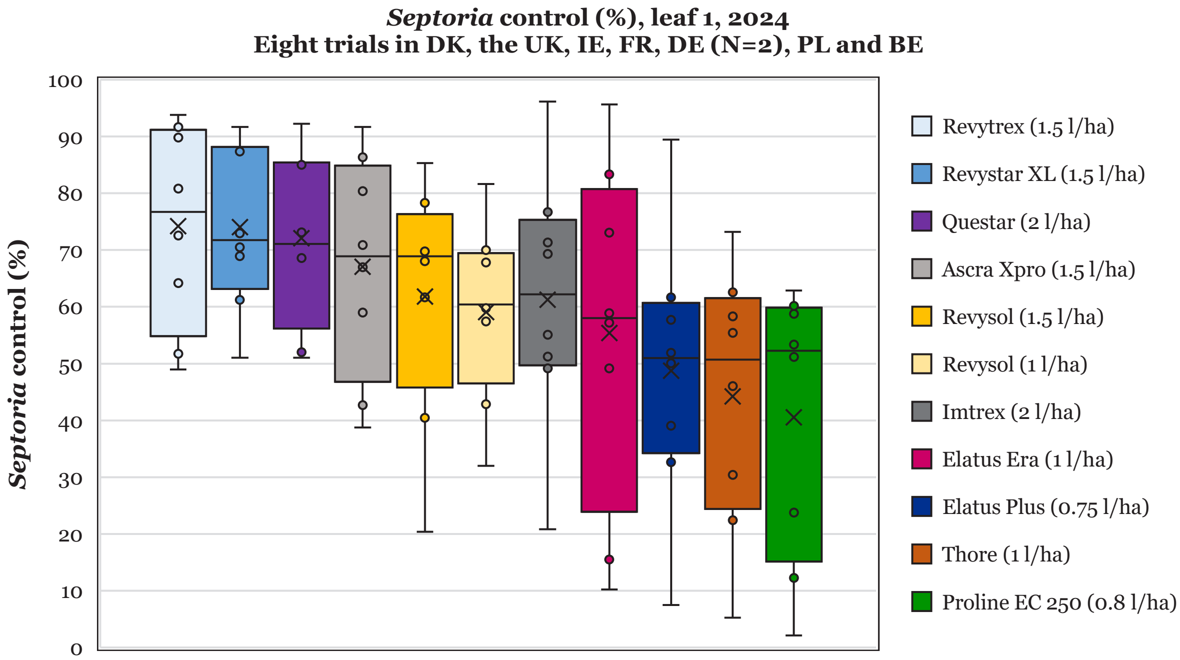


Figure 1. Control of *Septoria* on flag leaves. Average of eight trials in Denmark (DK), the United Kingdom (UK), Ireland (IE), France (FR), Germany (DE), Poland (PL) and Belgium (BE). Assessments were carried out at GS 71-75, 22-46 days after application (DAA).

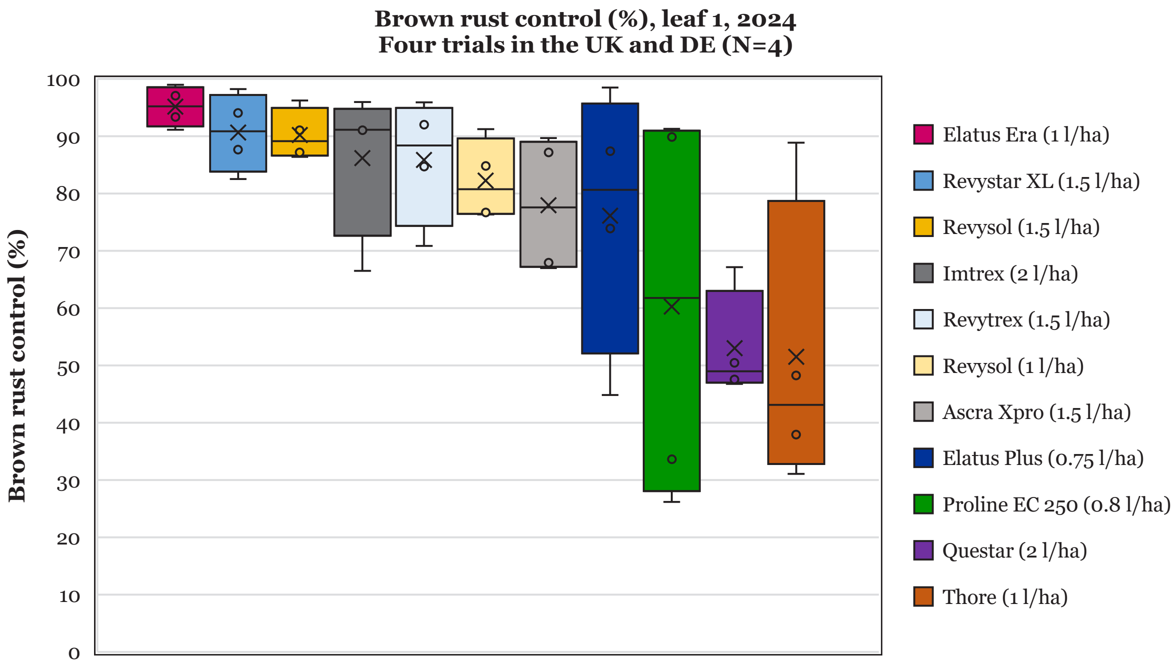


Figure 2. Control of brown rust in four EuroWheat trials from 2024, testing azoles, SDHIs, combination products and a QiI. The United Kingdom (UK) and Germany (DE).

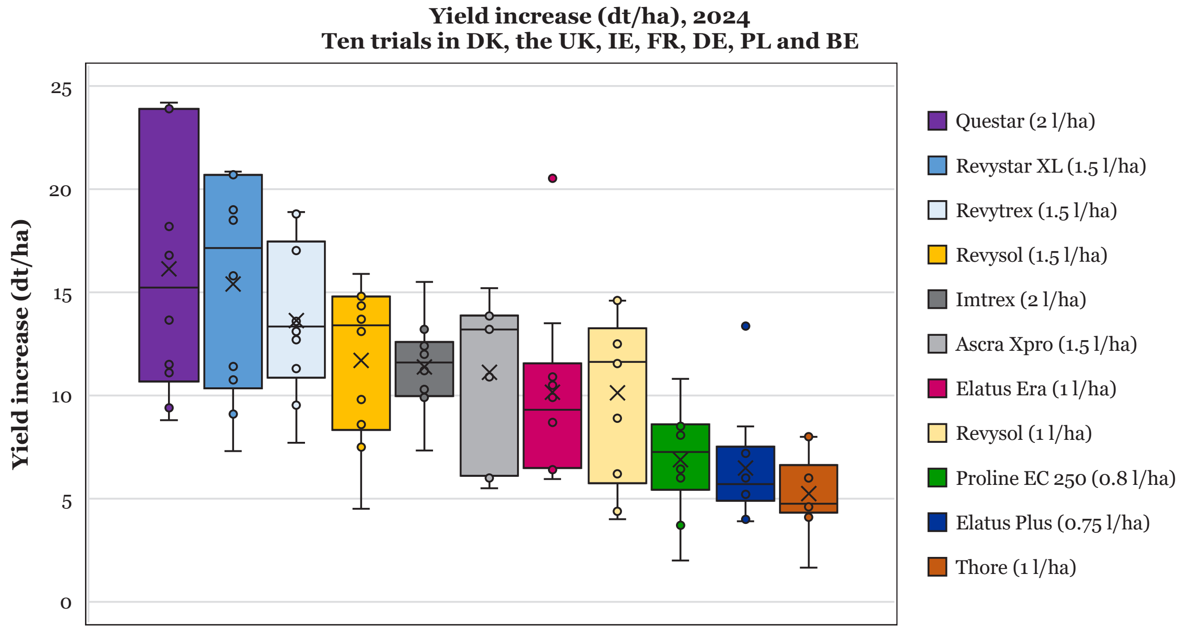


Figure 3. Yield increases from one flag leaf application in 10 trials carried out as part of the EuroWheat project. Denmark (DK), the United Kingdom (UK), Ireland (IE), France (FR), Germany (DE), Poland (PL) and Belgium (BE).

Testing azoles against Septoria tritici blotch (24329)

In line with previous years, several azoles were tested for control of Septoria tritici blotch, using two applications with half rates. Treatments were applied at GS 32-33 and GS 45-55. One trial was carried out at AU Flakkebjerg in the cultivar Hereford and the other one in Southern Jutland in the cultivar KWS Dawsum.

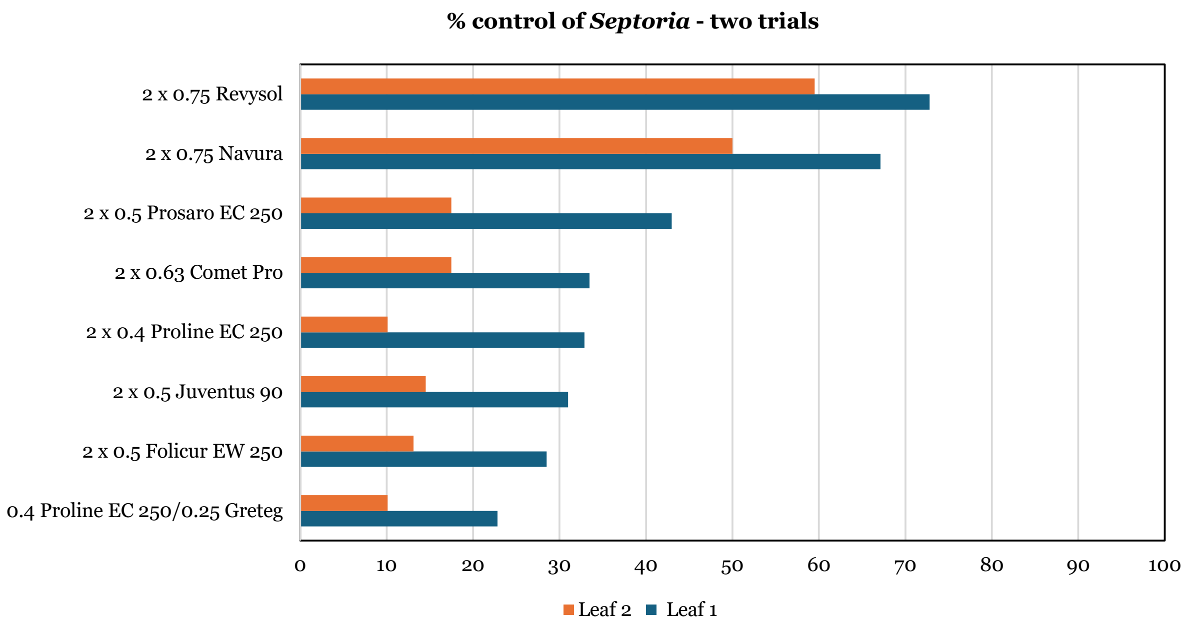
The data from the two trials are given in Table 4 and in many ways showed similar trends as in previous years. Although less efficacy was measured from all treatments, the efficacy of Revysol and Navura still outperformed the old azoles and Comet Pro. In this year's trials, Comet Pro resulted in control of *Septoria* in line with the old azoles. In the AU Flakkebjerg trial, a moderate attack of brown rust also developed, and all products except for Greteg (difenoconazole) and Proline EC 250 (prothioconazole) gave high levels of control (Figure 4). Comet Pro and the other azoles were very effective for control of brown rust.

All treatments increased yields significantly compared with untreated. Overall, the efficacies achieved were reflected in the yield responses obtained from the trials, where Revysol gave twice as high yield increases as the old azoles.

Table 4. Per cent attack of Septoria tritici blotch and brown rust. Green leaf area (GLA) and yield responses from treatments in winter wheat. Two trials in 2024 (24329).

Treatments, l/ha		% *Septoria*			% brown rust	% GLA	Yield & yield increase, dt/ha
GS 32-33	GS 51-55	GS 39-59 Leaf 3	GS 75 Leaf 2	GS 73-77 Leaf 1	Leaf 2	GS 83 Leaf 1	
1. Proline EC 250 0.4	Proline EC 250 0.4	16.5	26.9	17.7	11.2	46.9	5.2
2. Juventus 90 0.5	Juventus 90 0.5	14.8	26.9	18	0.9	51.9	4.7
3. Folicur EW 250 0.5	Folicur EW 250 0.5	15	25.6	18.8	0.3	53.8	4.8
4. Proline EC 250 0.4	Greteg 0.25	15.3	23.8	20.3	14.2	47.6	7.3
5. Prosaro EC 250 0.5	Prosaro EC 250 0.5	15.8	26.9	15	0.7	52.5	7.1
6. Revysol 0.75	Revysol 0.75	7.1	10.9	7.2	0.6	70.7	14.6
7. Navura 0.75	Navura 0.75	9.0	16.0	8.7	0.7	66.3	12.5
8. Comet Pro 0.625	Comet Pro 0.625	16.1	22.5	17.5	0.05	52.6	6.7
9. Untreated		21.9	34.4	26.3	22.3	41.3	85.2
No. of trials		2	2	2	1	2	2
LSD_{95}		2.4	4.1	5.2	7.7	7.3	3.2

Brown rust in wheat was more prevalent in 2024 than previously seen.



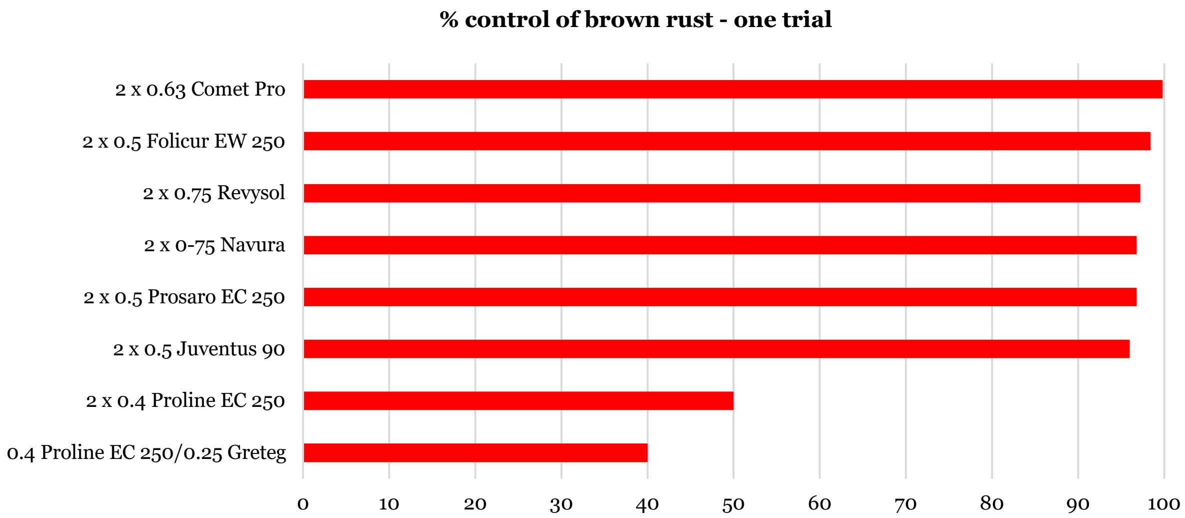


Figure 4. Per cent control of Septoria tritici blotch and brown rust, using two x ½ rates of different azoles. Average of two applications at GS 32-33 and GS 51-55. Per cent attack of *Septoria* was 26% and 42% on leaf 1 and 2, respectively, assessed at GS 75. Brown rust was scored at GS 75 with 25% severity on flag leaves in untreated.

The historical data from this protocol are shown in Figure 5, which visualises the major differences between the performances of old azoles and mefentrifluconazole (Revysol). As it can be noted, all azoles gave a reduced level of control compared with previous years, which most likely was caused by a more curative timing and relatively high disease levels. The reduced efficacy from the old azoles has stabilised at a similar control level since 2016, which also matches a major shift in sensitivity assessed in the laboratory (Chapter V). Only Revysol (mefentrifluconazole) performed significantly better than the old azoles. Also, the mixture of mefentrifluconazole + prothioconazole (Navura) performed in line with or slightly inferiorly to the solo mefentrifluconazole.

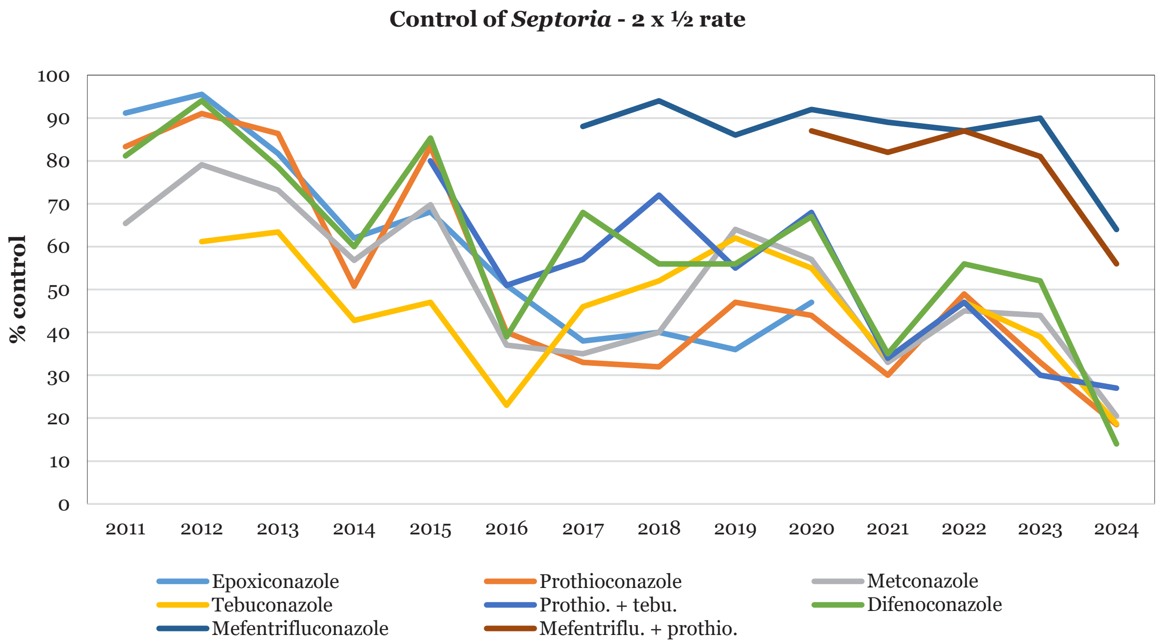


Figure 5. Per cent control of *Septoria*, using two x ½ rates of different azoles. Average of two applications at GS 32-33 and GS 51-55. Development of efficacy across years (2011-2024).

Comparison of available ear treatments (24325)

Three trials were conducted to test the efficacy of different fungicides at different dose rates when applied at heading (GS 39-40). This trial plan is a replication from previous years with only minor adjustments (Table 5). Two trials were located at AU Flakkebjerg in the cultivars Hereford and Cleveland, and one was located in Southern Jutland in a cultivar mixture. A cover spray was applied in most treatments at GS 31-32, using Proline EC 250 (0.2 l/ha). The trial tested dose responses of Balaya in comparison with older solutions. Balaya was tested at 50-100% of the full rate. Propulse SE 250 was tested at 75% normal rate mixed with either Folicur Xpert, Thiopron or Folpan 500 SC. In Chapter IX, the list of chemicals can be found with the label rates of the products.

Septoria developed a low to moderate level of attack in the trials on both the flag leaf and leaf 2. The control level was between 50% and 83% on leaf 1, and all treatments resulted in significant control (Figure 6). Only slight differences were seen between the control from the treatments on leaf 2. There was a clear dose response from Balaya on the control of *Septoria*. Full rate provided 83% control, while half rate provided 67% control. Adding Folpan 500 SC to half rate of Balaya increased control from 67% to 73%, and adding Folpan 500 SC to 0.75 l/ha Propulse SE 250 increased control from 50% to 56%. The mixture of Balaya and Propulse SE 250 gave overall a good control; however, mixing is only relevant if the strategy includes only one ear treatment as repeated use of SDHIs cannot be recommended.

Most solutions provided effective control of brown rust (Figure 7). The exceptions were 0.75 l/ha Propulse SE 250 mixed with Folpan 500 SC or Thiopron, confirming previous years' data which also have shown that Propulse SE 250 is a relatively weak rust control product.

Yields were increased from all the treatments by 8.4-13.7 dt/ha. All treatments resulted in a positive net yield as shown in Table 5. The early treatment at GS 31-32 did not increase the yields, which can be shown by comparing treatments 5 and 10. A minor positive and significant impact was measured on TGW from most treatments when compared with the untreated plots.

Table 5. Effect of T2 applications on control of *Septoria* and brown rust, yield responses and thousand grain weight (TGW) in wheat when treatments were applied at GS 39-40. Three trials (24325).

Treatments, l/ha			% *Septoria*			% brown rust	Yield & yield increase, dt/ha	Net yield, dt/ha	TGW, g
GS 31-32	GS 39-40	Dose, %	GS 65 Leaf 3	GS 75 Leaf 2	GS 77 Leaf 1	GS 77 Leaf 1			
1. Proline EC 250 0.2	Propulse SE 250 0.75 + Folicur Xpert 0.25	100	14.9	25.2	18.4	3.0	11.1	5.9	45.5
2. Proline EC 250 0.2	Propulse SE 250 0.75 + Folpan 500 SC 1.0	141	10.9	17.1	16.3	17.5	8.7	3.6	46.5
3. Proline EC 250 0.2	Propulse SE 250 0.75 + Thiopron 3.0	175	13.0	21.3	17.0	22.5	9.3	4.9	45.8
4. Proline EC 250 0.2	Balaya 0.75	50	11.8	19.1	12.1	0.1	9.3	4.9	46.8
5. Proline EC 250 0.2	Balaya 1.0	66	9.8	20.8	9.5	0.1	11.5	6.2	47.5
6. Proline EC 250 0.2	Balaya 1.5	100	8	13.3	6.3	0.0	13.7	6.6	48.9
7. Proline EC 250 0.2	Balaya 0.75 + Folpan 500 SC 1.0	116	11.5	14.3	10.0	0.1	13.0	7.5	46.3
8. Proline EC 250 0.2	Propulse SE 250 0.4 + Balaya 0.6	80	9.1	14.1	8.2	0.1	13.5	8.5	47.4
9. Proline EC 250 0.2	Greteg Star 0.5 + Propulse SE 250 0.5	100	12.0	22.8	12.3	2.0	8.4	4.1	46.5
10. Untreated	Balaya 1.0	66	12.1	18.8	11.2	0.1	11.1	7.0	47.4
11. Untreated	Untreated		28.75	39.6	37.7	30	90.4	-	42.7
No. of trials			3	3	3	1	3	3	3
LSD_{95}			4.3	4.27	2.9	3.2	2.7		1.5

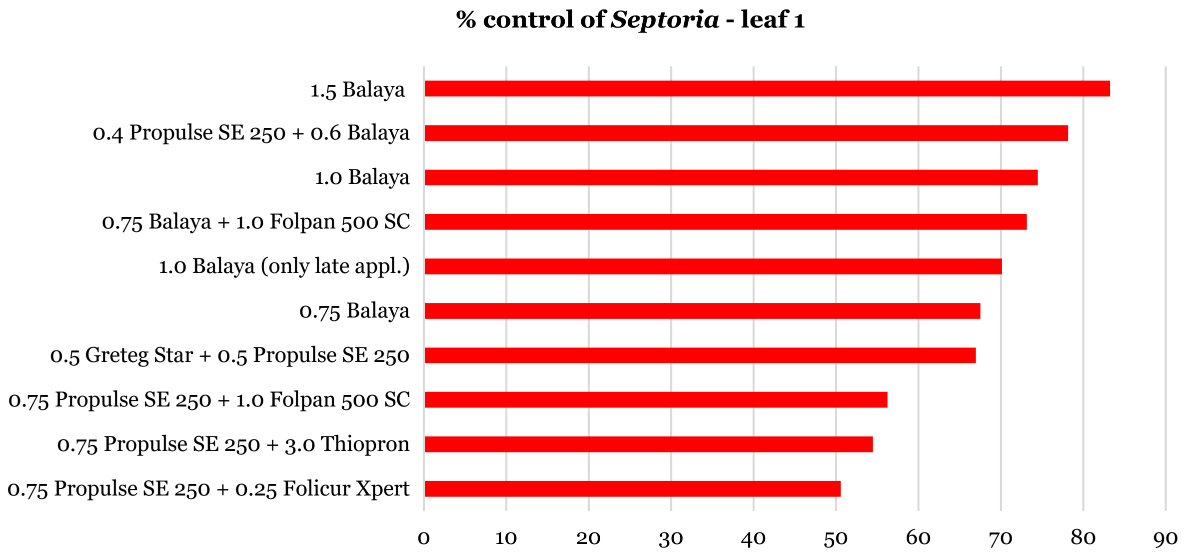


Figure 6. Per cent control of *Septoria* on the flag leaf. Average of three trials (24325) carried out in 2024. In the untreated plots, the attack reached 37.7% on leaf 1 when assessed at GS 75-77. At GS 31-32, 0.2 l/ha Proline EC 250 was applied in all treatments except treatment 10.

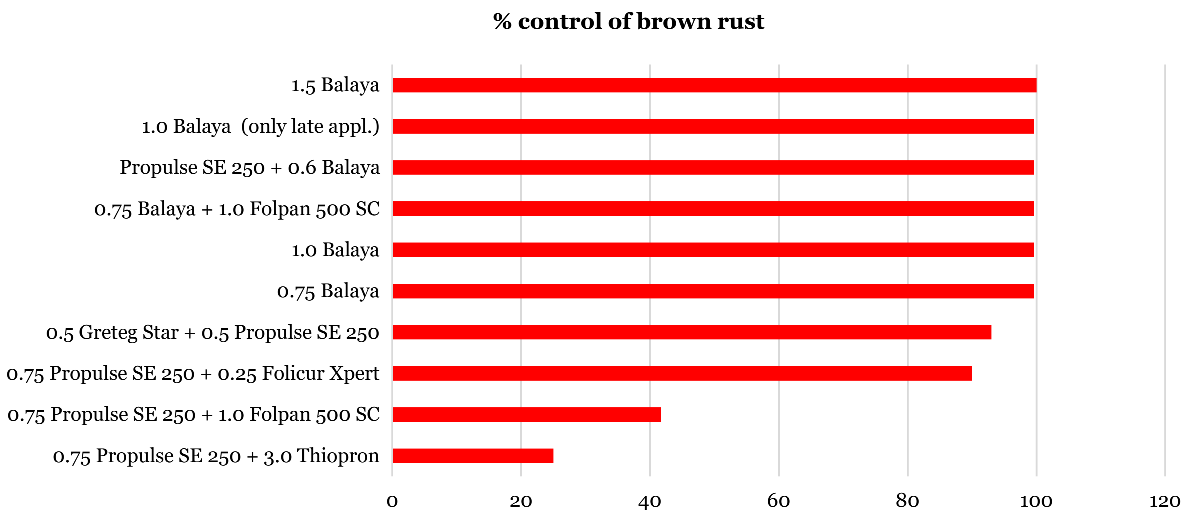


Figure 7. Per cent control of brown rust on the flag leaf in one trial (24325). In the untreated plots, the attack reached 50% on leaf 1 when assessed at GS 75-77. At GS 31-32, 0.2 l/ha Proline EC 250 was applied in all treatments except treatment 10.

Control strategies using two applications in winter wheat for control of *Septoria* (24326)

This trial protocol was conducted in three trials in two different cultivars (Hereford and Benchmark) at AU Flakkebjerg and in one trial in a cultivar mixture in Southern Jutland. This plan tested the efficacy of combinations of available products against both *Septoria* and yellow rust. T1 (GS 32) was a cover spray of 0.2 l/ha of Proline EC 250, T2 was applied at GS 37-39 and T3 at GS 61-65. The results are shown in Table 6.

The trial in Benchmark developed a significant attack of yellow rust. Most treatments provided effective rust control. However, treatments 3, 8 and 9, which relied mainly on Propulse SE 250 and Greteg Star at reduced rates, were inferior to other treatments (Figure 8). *Septoria* had a moderate to severe attack on the flag leaf; all treatments gave significant control (60-90%), shown in Table 6 and Figure 9. Adding Folpan 500 SC at both T2 and T3 provided a slight increase in control as seen in treatment 8. All treatments significantly increased the yields by 11 dt/ha to 18 dt/ha. The higher yield responses were harvested in Benchmark, which had a moderate to severe attack of yellow rust. Best net yields were measured in treatments 3, 5 and 6. There was a clear and significant improvement of TGW for all treatments. The highest increases in TGW were measured from the best yield increases. Even though the Danish number of products available is very small, good control and yield benefits from treatments can still be seen.

Table 6. Effect of split ear applications on control of *Septoria* and yellow rust, yield responses and thousand grain weight (TGW) in wheat. All treatments, including untreated plots, were treated with 0.2 l/ha Proline EC 250 at GS 32. Three trials (24326).

Treatments, l/ha		% *Septoria*			% yellow rust	Yield & yield increase, dt/ha	Net yield, dt/ha	TGW, g
GS 37-39	GS 61-65	GS 65-69 Leaf 3	GS 71-73 Leaf 2	GS 77-85 Leaf 1	GS 65 Leaf 2			
1. Untreated	Untreated	25	34.6	36.8	50	79.1	-	37.2
2. Propulse SE 250 0.75	Prosaro EC 250 0.5	12.3	14.1	19	7	11.8	7.3	40.6
3. Balaya 0.75	Greteg Star 0.35 + Propulse SE 250 0.35	10.7	10.3	15.8	17.5	17.2	11.7	42.2
4. Balaya 0.3 + Propulse SE 250 0.3	Propulse SE 250 0.75 + Folicur Xpert 0.25	12	10.8	13.5	5.8	15.3	9.5	40.8
5. Balaya 0.75	Propulse SE 250 0.75 + Folicur Xpert 0.25	10.3	10.2	14.3	4	17.7	11.2	43.1
6. Balaya 0.75	Propulse SE 250 0.5 + Pictor Active 0.5 + Agropol 0.2	9.6	8.1	9.1	4	18.6	11.7	42.3
7. Propulse SE 250 0.75	Navura 0.75	13.0	14.1	13.8	8.8	14.1	8.4	41.0
8. Balaya 0.5 + Folpan 500 SC 1.0	Propulse SE 250 0.5 + Folpan 500 SC 1.0	11.3	8.6	10.6	21.3	14.5	7.9	40.5
9. Balaya 0.5	Propulse SE 250 0.35 + Folpan 500 SC 0.75	13	13.8	15.7	27.5	11.5	6.7	41.1
No. of trials		3	3	3	1	3	3	3
LSD_{95}		2.3	3.1	5.2	9.5	3.4		1.8

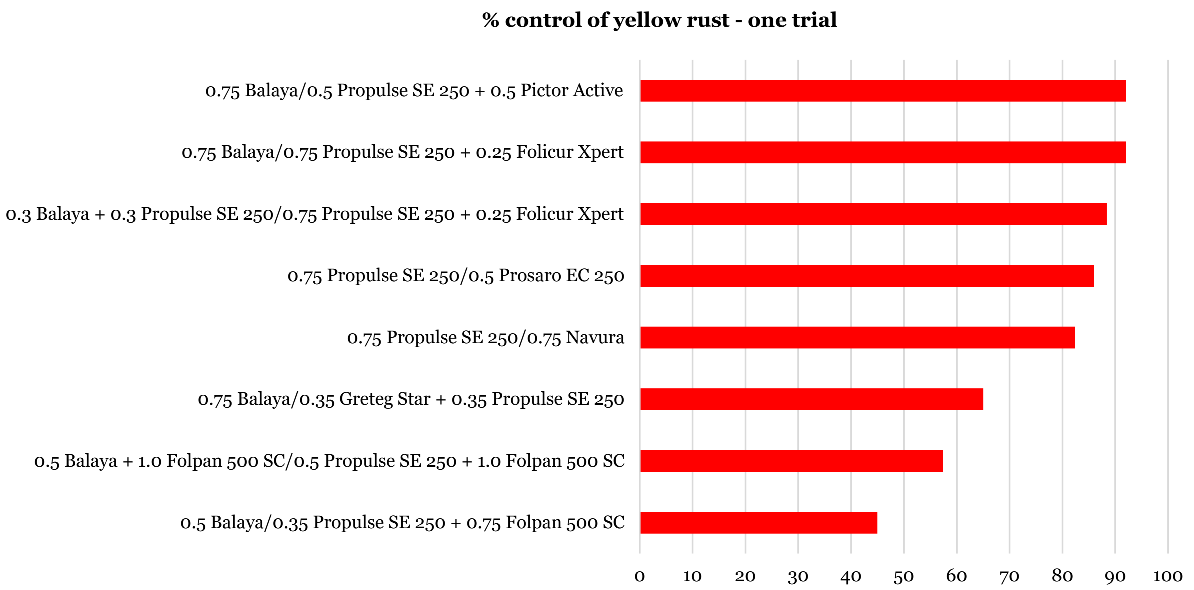


Figure 8. Per cent control of yellow rust on leaf 1 based on data from one trial (24326-3). In the untreated plots, the attack reached 50% on leaf 1.

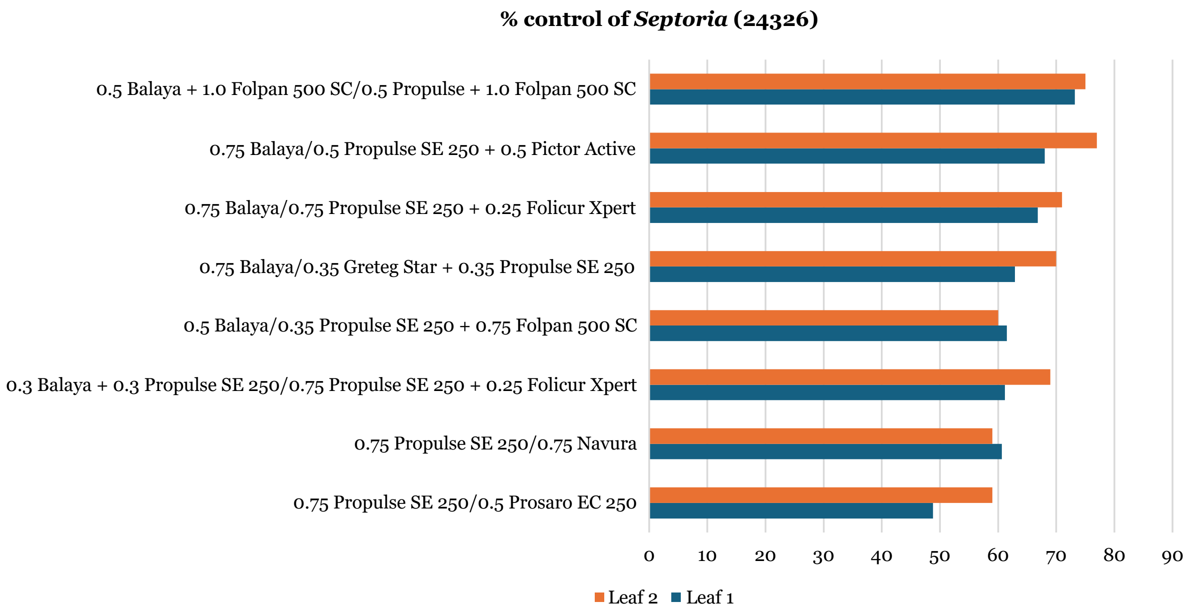


Figure 9. Per cent control of Septoria tritici blotch on leaf 1 and 2. Average of three trials (24326). In the untreated plots, the attack reached 35% on leaf 2 and 19% on leaf 1.

Testing of alternative chemistry and biological control agents (BCAs)

There is an increase in the need for alternative low-risk solutions to the standard chemicals, and it is becoming a priority for both the government and companies to search for alternatives. In this protocol, different alternative substances including different chemistries and biologicals were tested (Table 7). Two different sulphur products were tested (Vertipin and Thiopron), which are currently not authorised for use as crop protection products. Serenade ASO has a bacterium strain, *Bacillus amyloliquefaciens* QST 713, as its active ingredient. Bion 50 WG (benzothidazole) is known to induce systemic acquired resistance (SAR). Iodus uses seaweed plant extracts and has laminarin as its active ingredient, which is also known to induce the natural resistance of the plant. Revytur was also included and is a mixture of the azole mefentrifluconazole and sulphur. The different alternative compounds were compared to a reference using traditional chemical fungicides as well as to prothioconazole, which is a widely used azole.

Table 7. Effects of treatments at GS 32 and GS 39-45 on control of *Septoria* and brown rust, green leaf area (GLA), yield responses and thousand grain weight (TGW). One trial in 2024 in the cultivar LG Skyscraper (24322-1).

Treatments, l/ha		% *Septoria*			% brown rust	% GLA	Yield & yield increase, dt/ha	TGW, g
GS 32	GS 39-45	GS 71 Leaf 3	GS 75 Leaf 2	GS 75 Leaf 1	GS 75 Leaf 2	GS 83 Leaf 1		
1. Untreated		15.0	26.3	5.0	15	51.3	89.7	39.7
2. Propulse SE 250 0.5	Balaya 0.75	5.0	15.0	2.0	1	82.5	16.2	45.9
3. Proline EC 250 0.4	Proline EC 250 0.4	12.3	21.3	5.0	10	60	5.7	41.8
4. Thiopron 3.0	Thiopron 3.0	10.0	20.5	4,5	13.8	60	8.9	42.2
5. Phosphonate (DSPF016) 3.0	Revytur 2.0	10.5	17.0	3.0	8.0	72.5	12.3	43.4
6. Serenade ASO 2.0 + Silwet Gold 0.1%	Serenade ASO 2.0 + Silwet Gold 0.1%	12.0	21.0	4.5	10	60	1.3	41.3
7. Phosphonate (DSPF016) 3.0 + Thiopron 3.0	Phosphonate (DSPF016) 3.0 + Thiopron 3.0	7.8	17.0	3.0	9.3	62.5	6.7	42.4
8. Iodus 1.0	Iodus 1.0	12.0	24.3	5.0	10	62.5	3.1	41.7
9. Iodus 1.0 + Thiopron 3.0	Iodus 1.0 + Thiopron 3.0	11.0	17.8	3.0	9.3	65	5.7	42.8
10. Vertipin 3.5	Vertipin 3.5	10.0	20.0	4.5	15	60	6.6	41.7
11. Bion 50 WG 0.06 + Phosphonate (DSPF016) 3.0	Thiopron 3.0	8.5	17.8	3.0	13.5	63.8	7.1	40.8
15. Folpan 500 SC 1.5 + Thiopron 3.0	Folpan 500 SC 1.5 + Thiopron 3.0	5.5	18.5	3.3	14.3	68.8	7.4	41.8
LSD_{95}		1.4	3.1	0.79	3.2	6.3	5.6	2.3

This protocol was conducted in the cultivar LG Skyscraper at AU Flakkebjerg. In the trial, two treatments were applied at GS 32 and at GS 39-45. All products had some level of control. Overall, the control level from the alternative substances was low and inferior to the traditional chemical treatments 2. This was the case for control of both Septoria tritici blotch and brown rust (Figure 10). Initially, an improved control of Septoria tritici blotch was seen when Folpan 500 SC was added. As seen in previous seasons, sulphur products gave some level of control, which was in line with the effect from prothioconazole. Late in the season, all treatments gave very minor levels of control. Green leaf area was only improved significantly for treatments 2 and 4, indicating that the effects of the alternatives are less persistent than those of the traditional chemistries. Only little control effect was obtained on brown rust from all alternative products, and sulphur products gave almost no control of this disease.

Only four of the tested solutions improved yields significantly compared with untreated. This was the case for treatments 2, 4, 5 and 15. For five of the treatments, a significant improvement was also measured in the TGW.

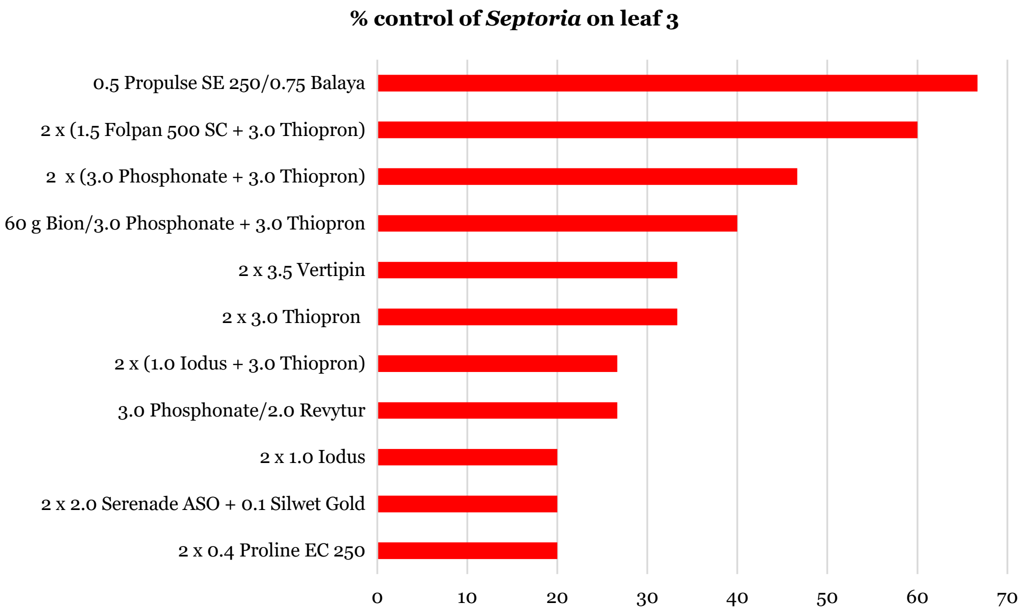


Figure 10. Per cent control of *Septoria* in two wheat trials (24322), using two applications at GS 32 and GS 39-45.

Baltic T1 and T2 solutions for control of *Septoria*

Three different trial plans were carried out with the aim of testing different T1 at GS 32-33 and T2 at GS 39-51 solutions against *Septoria*, using treatments which are authorised in the Baltic region and in several other countries in Europe. The only products included in these trial plans which are approved for use in Denmark are Balaya, Proline EC 250, Amistar and Flexity.

Trial 24332 tested different T1 combinations and used a similar cover spray at T2 (0.5 l/ha Balaya). The trial was carried out in the cultivar Cleveland (Table 8). Septoria tritici blotch infections developed moderate attacks, and assessments on leaves 3 and 4 at GS 59 and 69 showed that the best control was from treatments 3 and 10, which included Input Triple and Revystar XL at T1. Revystar XL provided the best control on leaf 2 at GS 69. At later assessments, all treatments provided similar control following a similar treatment at T2 with Balaya.

All treatments increased yields significantly, but also here the Revystar XL treatment stood out as the best yielding treatment (15.2 dt/ha). TGWs were also significantly improved from most treatments.

Trial 24333 tested different T2 combinations and used a similar cover spray at T1 (0.5 l/ha Balaya). The trial was carried out in the cultivar LG Skyscraper (Table 9). Septoria tritici blotch infection developed moderate to severe attacks, and moderate attacks of brown rust were also assessed. All treatments gave very similar and good control of *Septoria* on the two upper leaves at GS 75. Elatus Era was least effective against *Septoria* at the latest assessments. Univoq gave slightly better control of *Septoria* at GS 73 (leaf 3) and GS 75 (leaf 2) but was less effective on brown rust.

All treatments increased yields significantly, and the mixture of Revystar XL + Priaxor gave the best yield increase (15.3 dt/ha), which was significantly better than that of Elatus Era (8.5 dt/ha). TGWs were also significantly improved by all treatments.

Trial plan 24334 investigated the effects from different fungicide combinations applied at both T1 and T2 treatments, all products being relevant for the Baltic region. The trial was carried out in the cultivar Hereford (Table 10). Septoria tritici blotch infection developed moderate to severe attacks, and moderate to severe attacks of brown rust were assessed. On leaf 4, the efficacy from treatments 2, 3 and 7 was inferior to other treatments mainly relying on efficacy from T1, where Proline EC 250 + Amistar, Input Triple and Daxur were applied and provided less overall control. At later assessments, treatments 6 and 8, which contained Priaxor + Innox/Revytrex or Revystar XL + Priaxor/Univoq, stood out as the most effective solutions. Regarding control of brown rust, all solutions gave high levels of control except for treatment 8 using Revystar XL + Priaxor/Univoq, which was inferior.

All treatments increased yields significantly, and only the Elatus Era solution was significantly inferior to other treatments. TGWs were significantly improved by all treatments.

Table 8. Effects of treatments at GS 32-33 and GS 45-51 on control of *Septoria*, green leaf area (GLA), yield responses and thousand grain weight (TGW). The trial was carried out in the cultivar Cleveland (24332).

Treatments, l/ha		% *Septoria*				% GLA	Yield & yield increase, dt/ha	TGW, g
GS 32-33	GS 45-51	GS 59 Leaf 4	GS 69 Leaf 3	GS 69 Leaf 2	GS 75-77 Leaf 1	GS 77-83 Leaf 1		
1. Untreated		42.5	23.8	33.8	23.8	1.8	83.0	45.6
2. Proline EC 250 0.4 + Amistar 0.4	Balaya 0.5	35.0	16.8	25.0	6.5	32.5	9.4	48.1
3. Input Triple 0.75	Balaya 0.5	22.5	5.5	22.5	6.5	28.8	10.1	48.6
4. Delaro Forte 1.0	Balaya 0.5	33.8	16.3	20.0	6.5	21.3	10.2	46.9
5. Verben 0.75	Balaya 0.5	27.5	16.5	23.5	5.0	17.5	9.6	46.9
6. Priaxor 0.4 + Innox 0.4	Balaya 0.5	31.3	9.8	20.3	4.0	33.8	12.6	47.9
7. Daxur 1.0	Balaya 0.5	30.0	18.0	23.0	5.8	18.8	11.6	47.1
8. Revytrex 0.8	Balaya 0.5	31.3	12.3	22.8	5.0	22.5	11.6	49.8
9. Balaya 0.5 + Flexity 0.25	Balaya 0.5	26.3	11.0	21.8	6.5	30.0	11.3	45.1
10. Revystar XL 0.4 + Priaxor 0.4	Balaya 0.5	21.3	6.8	17.8	5.8	32.5	15.2	48.2
11. Navura 1.0	Balaya 0.5	26.3	18.8	20.0	7.5	25.0	12.7	48.2
LSD_{95}		5.0	3.0	2.8	2.8	15.9	4.7	3.0

Table 9. Effects of treatments at GS 32-33 and GS 45-51 on control of *Septoria* and brown rust, green leaf area (GLA), yield responses and thousand grain weight (TGW). The trial was carried out in the cultivar LG Skyscraper (24333).

Treatments, l/ha		% *Septoria*				% brown rust	% GLA	Yield & yield increase, dt/ha	TGW, g
GS 32-33	GS 45-51	GS 65-69 Leaf 3	GS 73 Leaf 3	GS 75 Leaf 1	GS 75 Leaf 2	GS 75 Leaf 2	GS 77 Leaf 1		
1. Untreated		8.5	50	18.6	70	7.0	32.5	102.3	43.3
2. Balaya 0.5	Elatus Era 0.75	2.8	17.8	1.9	30	0.0	48.8	8.5	46.9
3. Balaya 0.5	Ascra Xpro 1.0	3.0	17.8	1.1	25	0.0	51.3	9.7	46.0
4. Balaya 0.5	Univoq 1.2	3.5	15	0.9	11.3	1.0	58.8	11	47.5
5. Balaya 0.5	Balaya 1.0	2.8	18	1.4	20	0.0	60.0	10.9	47.2
6. Balaya 0.5	Priaxor 0.5 + Innox 0.5	1.8	21.3	1.4	22.5	0.0	46.3	10.6	46.4
7. Balaya 0.5	Revystar XL 0.5 + Priaxor 0.5	3.5	22.5	1.2	28.8	0.0	52.5	15.3	47.8
8. Balaya 0.5	Revytrex 1.0	2.3	17.8	0.8	18.8	0.0	62.5	9.5	46.3
LSD_{95}		1.7	3.2	5.5	8.0	1.9	9.0	6.6	1.65

Table 10. Effects of treatments at GS 32 and GS 39-45 on control of *Septoria* and brown rust, green leaf area (GLA), yield responses and thousand grain weight (TGW). The trial was carried out in the cultivar Hereford (24334-1).

Treatments, l/ha		% *Septoria*				% brown rust	% GLA	Yield & yield increase, dt/ha	TGW, g
GS 32	GS 39-45	GS 55-59 Leaf 4	GS 73 Leaf 3	GS 75 Leaf 1	GS 75 Leaf 2	GS 75 Leaf 2	GS 78 Leaf 1		
1. Untreated	Untreated	25.0	50.0	21.8	60.0	37.5	27.5	80.3	40.5
2. Proline EC 250 0.4 + Amistar 0.4	Elatus Era 0.75	17.5	27.5	1.8	26.3	0.0	60	12.3	47.0
3. Input Triple 0.75	Ascra Xpro 1.0	21.0	19.3	1.4	28.8	1.0	65	21.9	45.8
4. Balaya 0.5 + Flexity 0.25	Revytrex 1.0	11.8	17.3	1.2	16.3	0.0	67.5	19.4	46.4
5. Revytrex 0.5	Revystar XL 0.5 + Priaxor 0.5	15.5	12.3	0.7	12.5	0.0	68.8	17.3	46.2
6. Priaxor 0.4 + Innox 0.4	Revytrex 1.0	12.5	17.8	0.4	8.8	0.0	70	20.6	46.7
7. Daxur 1.0	Balaya 1.0	20.5	25.0	1.8	18.8	0.0	68.8	17.7	47.0
8. Revystar XL 0.4 + Priaxor 0.4	Univoq 1.2	14.3	12.8	0.2	5.0	6.3	58.8	20.2	46.5
9. Revystar XL 0.4 + Priaxor 0.4	Revytrex 1.0	11.8	15.3	0.6	13.8	0.0	68.8	19.5	46.6
LSD_{95}		4.44	3.6	0.6-8.1	5.6	1.9	4.7	7.7	1.7

Testing different T1 treatments against powdery mildew

This trial tested different fungicides against mildew at T1 (GS 31-32), and no further treatments were applied at T2 (Table 11). This trial was carried out near Agerskov in the cultivar Champion. In this trial, three dose rates of Talius EC were tested along with other mildewicides.

Powdery mildew developed to moderate but significant levels during the season. All the treatments helped control the powdery mildew. Initially, the control levels were moderate and best from application of Proline EC 250, Vegas and Univoq. There was a very limited dose effect from Talius EC. Only at the very late assessments did the higher rates have the best lasting control, which in this year's trial was in line with the control from Vegas. Compared with the effects achieved from Talius EC in previous seasons, this year's data were only showing very limited control. Unfortunately, no sample of mildew was checked for possible sensitivity changes. But the data clearly indicate that further testing is needed to check for possible shifting in the sensitivity of the population.

Yields increases were limited: between 0 dt/ha and 8 dt/ha. The treatments which also had an effect on Septoria tritici blotch provided a better and significant yield increase compared with products which only had an effect on powdery mildew (Talius EC, Vegas, Flexity). Only limited and insignificant effects were seen on TGW.

Table 11. Effects of treatments at GS 32 on control of powdery mildew and *Septoria*, yield responses and thousand grain weight (TGW). One trial in 2024 in the cultivar Champion (24310-1). Several treatments are not included due to confidentiality.

Treatments, l/ha	% powdery mildew					% *Septoria*	Yield & yield increase, dt/ha	TGW, g
	GS 32 Leaf 4	GS 32 Leaf 5	GS 43 Leaf 3	GS 43 Leaf 2	GS 53 Leaf 3	GS 53 Leaf 3		
1. Talius EC 0.15	7.1	2.2	7.7	5.3	8.9	10.0	2.1	41.6
2. Talius EC 0.2	6.0	2.0	8.4	5.5	8	9.5	0.7	42.2
3. Talius EC 0.25	5.0	2.3	5.9	4.8	3.4	10.0	0.1	42.6
5. Proline EC 250 0.65	1.2	0.6	4.4	3.0	5.3	7.0	7.3	44.4
6. Vegas 0.5	1.3	0.4	2.7	2.0	3.1	10.3	3.6	42.8
7. Flexity 0.5	8.0	2.9	7.4	4.5	7.1	9.5	2.4	42.0
8. Univoq 1.0	0.7	0.3	2.1	2.3	2.7	15.0	8.8	40.8
9. Untreated	12.3	13.6	11.0	7.8	15.7	2.8	83.8	41.9
LSD_{95}	4	2.2	3.8	1.7	4.5	2.5	3.0	NS

Tan spot (*Pyrenophora tritici-repentis*) in wheat cultivars – ranking of cultivar susceptibility

The trial was organised with four replicates and 2 x 1 m row per plot. The area was inoculated in the autumn with debris of tan spot inoculum, which is known to provide good attack in the following season. The trial in 2024 was attacked by significant infections of tan spot and almost no *Septoria*. The trial was assessed at four timings (GS 32, 71, 75 and 77) during the season. The weather was moderately conducive to the development of attack.

Most cultivars are known to be quite susceptible to tan spot and only few of the currently relevant cultivars (Pacman, Creator, Informer and Pondus) had a lower level of attack than most of the other cultivars. Figure 11 shows the results for attack of % tan spot, ranking the cultivars according to susceptibility. Creator, Pondus and Informer also showed a better level of control in previous seasons.

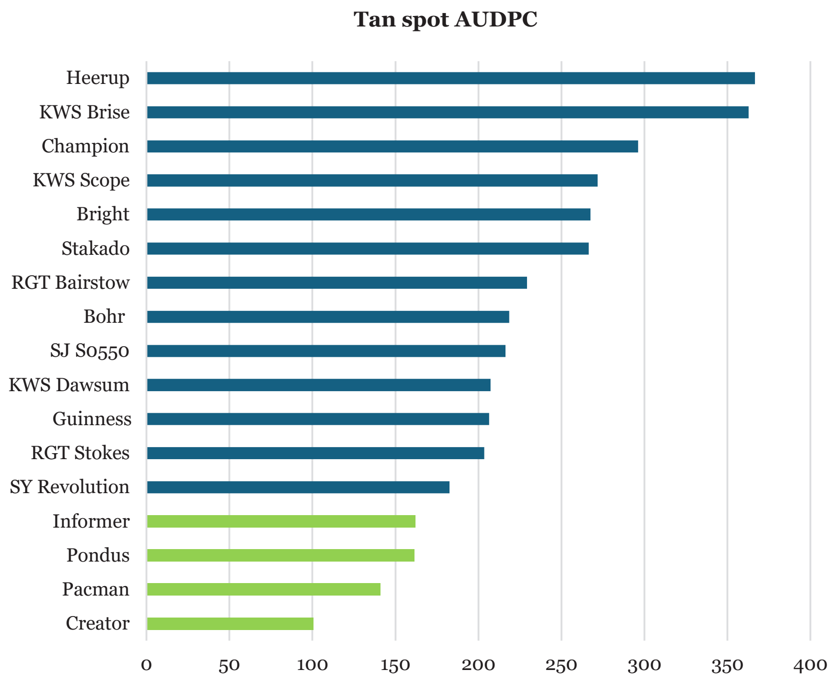


Figure 11. Infection of tan spot in different winter wheat cultivars. Based on four assessments on the upper leaves (24302-1), calculating AUDPC (Area Under Disease Pressure Curve). LSD_{95} = 93.

Ranking susceptibility to Fusarium head blight in winter wheat in 2024

In line with previous years, the Department of Agroecology, Aarhus University, AU Flakkebjerg, investigated the susceptibility to Fusarium head blight (FHB) in a project partly financed by the breeders. The tested cultivars are commonly grown in Denmark or are cultivars expected to become important in the years to come. In this year's two trials (24301-1/2), 15 cultivars were included. One trial was inoculated during flowering; the other trial was inoculated with infested grain placed on the ground during elongation (GS 33-39) (20 May). Two rows of 1 metre of each cultivar were sown in the autumn, and four replicates were included. The trial was inoculated three times, on 3, 7 and 10 June, respectively, 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 two 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. The first symptoms of FHB were seen approximately 15 days after inoculation.

Both trials were 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 0-10 scale. The results from the final scoring of infection degree of the heads are shown in Figures 12 and 13. As seen in Figure 12, the cultivars KWS Scope, Heerup and Kvium were the most susceptible. Least attack was seen in KWS Dawsum, Sheriff and Pondus. The cultivar Ritmo was used as the susceptible reference cultivar and Skalmeje as the most resistant reference. Data from the two trials correlated quite well as can be seen in Figure 12.

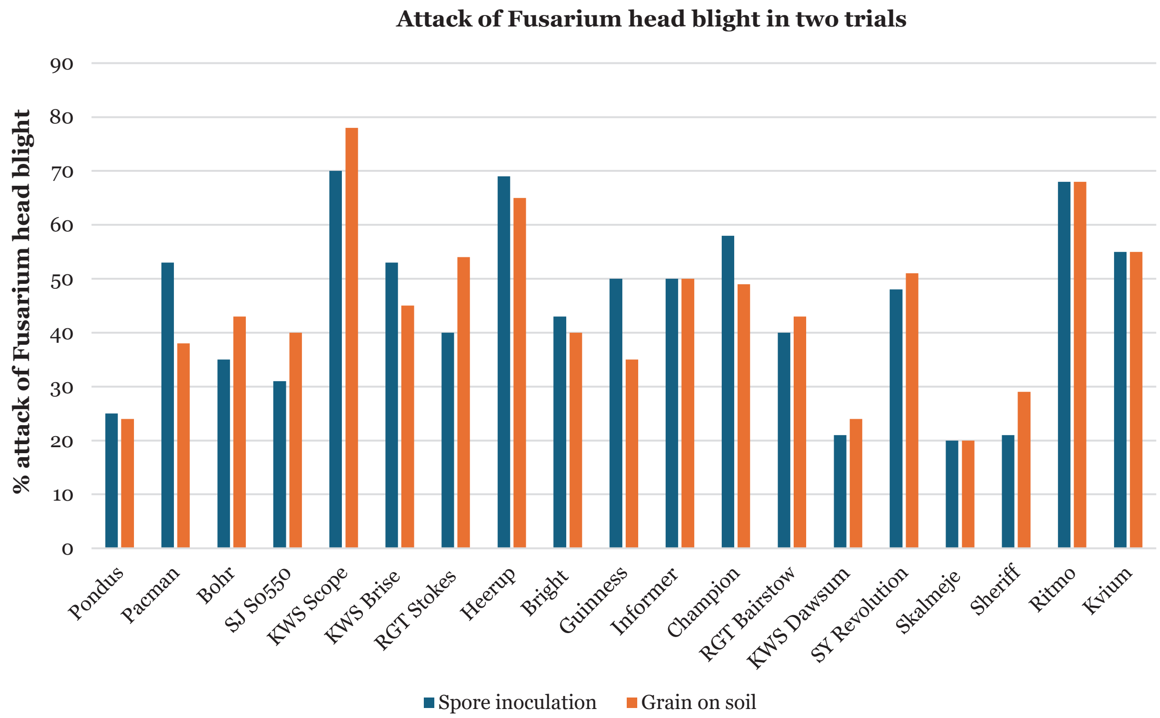


Figure 12. Per cent attack of Fusarium head blight in different cultivars tested in two wheat trials infected by different methods. Two trials in 2024 (24301).

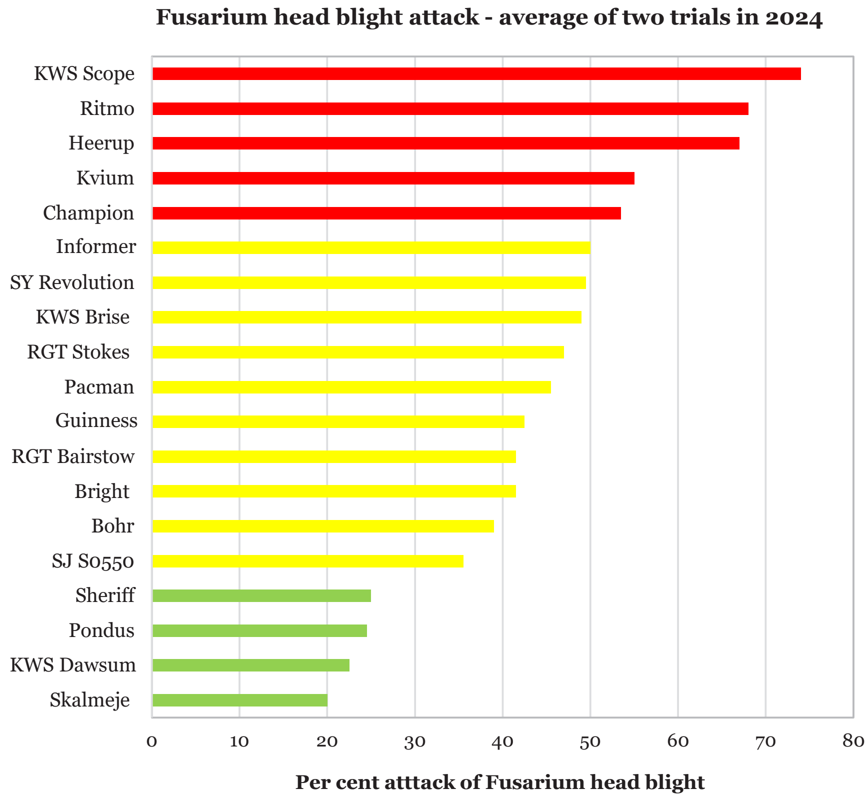


Figure 13. Percentage of ears in different cultivars attacked by Fusarium head blight in July 2024. Average of two trials (24301).

The small plots in both trials were hand harvested, and grains were tested for the content of the mycotoxins, using HPLC-MSMS. Three toxins were measured: deoxynivalenol (DON), nivalenol (NIV) and zearalenone (ZEA). All cultivars had high DON levels – much higher than the maximum acceptable limit of 1250 ppb. In this year's trials, a poor correlation was found between *Fusarium* infections and DON content ($R^2 = 0.03$) (Figure 14).

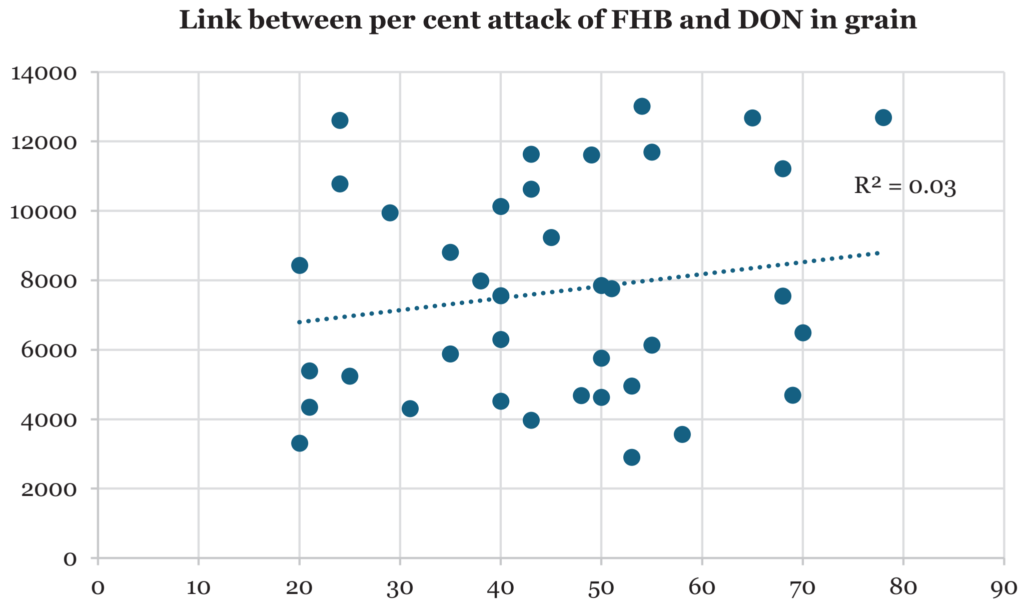


Figure 14. Correlation between deoxynivalenol (DON) content measured as ppb and % Fusarium head blight (FHB) attack from the two trials in 2024 (24301).

III Disease control in barley

Brittany Deanna Beck, Niels Matzen, Hans-Peter Madsen, Sofie Rosengaard Nørholm, Christian Appel Schjeldahl Nielsen, Anders Almskou-Dahlgaard & Lise Nistrup Jørgensen

In this chapter, the field trials are following the same experimental protocol as stated in Chapter II: Disease control in wheat. Here, we present results from barley trials.

Control of diseases using alternative solutions in barley

In one trial, alternative solutions were tested in spring barley against multiple diseases. This was conducted in the cultivar RGT Planet. The different alternatives are listed in Table 1. Two different sulphur treatments were tested (Vertipin and Thiopron), which are currently not authorised for use as crop protection products in Denmark. Serenade ASO with the bacterium strain *Bacillus amyloliquefaciens* QST 713 was included and so was Iodus, which is based on seaweed extracts and has laminarin as its active ingredient. Laminarin is known to induce the natural resistance of the plants. This was used alone as well as in a mixture with phosphonate.

There were a medium infection rate of net blotch (*Pyrenophora teres*) and severe infections of brown rust (*Puccinia hordei*), as shown in Table 1. All treatments gave significant reductions of net blotch. The alternative products were, however, still inferior to the two standard treatments using Propulse SE 250 or Proline EC 250. No clear differences in control were seen between the alternative solutions. Significant yield increases were recorded from the two chemical references, while none of the alternatives increased yields significantly. The yield data were supported by thousand grain weight (TGW), which also showed a significant increase in values for the two references, but not for the alternatives.

Table 1. Disease attack, thousand grain weight (TGW) and yield responses, using alternative products to traditional fungicides applied twice at GS 31-32 and 51-55 in spring barley. One trial (24387) in RGT Planet.

Treatments, l/ha		% net blotch	% rust		TGW, g	Yield & yield increase, dt/ha
GS 31-32 / 51-55	Dose	GS 71 Leaf 2	GS 71 Leaf 3	GS 71 Leaf 1		
1. Untreated		12.5	47.4	32.5	35.2	35.6
2. Propulse SE 250	0.5	2.8	18.5	10	38.6	7.0
3. Proline EC 250	0.4	3.5	12.4	8.8	40.5	9.3
4. Thiopron	3.0	7.5	42.4	28.8	34.6	0.0
5. Phosphonate	3.0	6.3	40.0	28.8	34.7	-0.4
6. Serenade ASO + Silwet Gold	2.0 + 0.1	6.5	40.0	28.8	34.3	-0.1
7. Phosphonate + Thiopron	3.0 + 3.0	8.3	40.0	28.8	34.8	1.1
8. Iodus	1.0	7.0	40.0	28.8	34.8	0.1
9. Iodus + Thiopron	1.0 + 3.0	8.8	42.4	30.0	33.4	0.5
10. Vertipin	3.5	8.8	42.4	28.8	34.6	-1.0
LSD_{95}		4.5	3.2	2.3	1.6	1.9

Comparison of market-related solutions in spring barley

Two trials were carried out in spring barley at AU Flakkebjerg. The aim of the trial plan was to test different fungicide solutions, typically using 50-65% of the approved rates. Furthermore, the trial aimed to investigate and compare the efficacy of the relevant solutions from 2024, typically mixtures, against all the relevant leaf diseases in barley. The trials were carried out in the cultivars Skyway and RGT Planet.

Results from the two spring barley trials are shown in Table 2 and Figure 1. The trials developed moderate to severe attacks of net blotch (*Pyrenophora teres*), Ramularia leaf spot (*Ramularia collo-cygni*) and brown rust (*Puccinia hordei*). Most of the tested solutions provided very similar and good control of the diseases. The effect on net blotch, Ramularia leaf spot and brown rust is also shown in Figure 1. The level of control of Ramularia leaf spot was relatively low but best from applying the mixture of Balaya + Propulse SE 250, followed by Navura. Yield levels were relatively low, but even so, the responses from fungicides were significant, varying between 4.2 dt/ha and 13.7 dt/ha. Treatments giving least control of brown rust also gave the lowest yield increases (Table 2). This was the case for the tank mixture of Propulse SE 250 + Thiopron as well as Navura.

Table 2. Disease attack, green leaf area (GLA), thousand grain weight (TGW) and yield responses, using different fungicides applied at half rates at GS 37 in spring barley. Two trials in 2024 (24384).

Treatments, l/ha		% net blotch	% *Ramularia*		% brown rust	% GLA	TGW, g	Yield & yield increase, dt/ha	Net increase, dt/ha
GS 37	Dose	GS 51 Leaf 3	GS 73 Leaf 2	GS 77 Leaf 2	GS 71 Leaf 2	GS 77 Leaf 2			
1. Propulse SE 250 + Comet Pro	0.6 + 0.2	2.50	35.6	63.4	0.91	36.9	42.0	11.22	32.14
2. Propulse SE 250 + Comet Pro	0.3 + 0.3	2.50	40.0	67.5	1.09	34.6	42.6	12.53	28.42
3. Propulse SE 250 + Thiopron	0.25 + 3.0	2.56	53.1	90.6	18.13	12.5	37.7	4.19	5.20
4. Balaya + Propulse SE 250	0.5 + 0.25	2.50	25.0	57.1	1.56	44.8	42.7	13.74	41.83
5. Navura	1.0	2.63	35.6	76.6	2.50	26.8	40.8	8.51	-
6. Soratel + Pictor Active + Agropol	0.4 + 0.4 + 0.2	2.63	40.0	65.0	0.66	39.2	42.6	13.18	42.18
7. Untreated		3.88	71.9	97.6	24.38	7.4	34.9	49.54	-
No. of trials		2	2		2	2	2	2	2
LSD$_{95}$		0.5	5.2	8.8	3.4	10.3	2.23		

Figure 1. Per cent control of net blotch, brown rust and Ramularia leaf spot (two trials) in spring barley. Leaves were assessed at GS 77. Attack in untreated plots was 4.6% net blotch, 25% brown rust and 72% *Ramularia* (24384).

Control of Ramularia leaf spot in the EuroBarley project

Ramularia leaf spot (RLS) is becoming a concern in barley because of its adapted resistance to several groups of fungicides in multiple regions across Western Europe, causing the future control strategies to be under pressure. The pathogen has been found to be extremely diverse, and these diversities are found in multiple regions of Europe, which makes it a challenging disease to control.

Ramularia leaf spot has developed resistance to strobilurins (QoIs). This group of actives used to have a good efficacy against RLS. Several mutations in the target genes of SDHIs have been detected in the population of *R. collo-cygni* (e.g. B-H266Y/R, B-T267I, B-I268V, C-N87S, C-H146R and C-H153R) with increasing frequency since 2014. Additionally, azole-adapted isolates of *R. collo-cygni* have been found at high frequencies in several European countries.

In line with trials from 2021-23, the trials in 2024 tested several different combinations of fungicides applied at GS 45-51 as part of the EuroBarley project. Data from previous seasons have been published in a reviewed paper (Matzen et al., 2024). In the *Ramularia* trials, 0.5 l/ha Comet Pro was applied during elongation to keep down attacks of rust and other leaf blotch diseases.

A trial in 2024 carried out at AU Flakkebjerg as part of the EuroBarley project used a trial plan similar to those used in three other countries (Germany, Ireland and Scotland). The Danish trial developed late but severe infections of Ramularia leaf spot, which resulted in good options for evaluating the efficacy of the different products (Table 3). In Denmark, only Proline EC 250 stood out from the other treatments, and this treatment only provided 19% control from the full dose (Figure 2). Folpan 500 SC gave surprisingly good results compared with results from previous seasons (Matzen et al., 2024). As also seen in previous years, BAS 831 00F provided the best control of RLS and also the best yield response.

Table 3. Attack of barley rust, net blotch and *Ramularia* leaf spot, thousand grain weight (TGW) and yield responses, using different fungicides applied at GS 45-51 in spring barley (24386). Danish trial as part of the EuroBarley project.

Treatments, l/ha		% barley rust	% net blotch	% *Ramularia*			TGW, g	Yield & yield increase, dt/ha
GS 45-51	Dose	GS 71 Leaf 2	GS 71 Leaf 2	GS 71 Leaf 2 17D AA	GS 75 Leaf 2 21 DAA	GS 77 Leaf 2 25 DAA		
1. Untreated		3.0	2.0	19.95	67.50	84.5	40.9	54.6
2. Revysol	1.0	0.58	0.3	3.36	26.75	68.8	43.8	5.06
3. Revysol	1.5	0.28	0.35	2.56	25.0	63.0	45.1	6.22
4. Proline EC 250	0.54	0.63	0.28	14.59	61.25	77.0	44.2	2.50
5. Proline EC 250	0.8	1.0	0.48	16.20	55.0	74.0	42.9	3.81
6. Folpan 500 SC	1.5	0.5	0.28	5.03	12.0	28.8	45.1	4.38
7. Elatus Era	1.0	0.5	0.35	2.98	25.50	60.0	46.7	7.72
8. Ascra Xpro	1.2	0.5	0.30	3.73	22.50	65.0	46.2	7.43
9. Revytrex	1.5	0.45	0.20	3.76	31.75	62.5	43.9	5.95
10. Revystar XL	1.5	0.38	0.20	1.28	18.50	60.0	44.1	6.32
11. BAS 831 00F	2.25	0.2	0.20	0.15	1.88	11.8	48.5	11.39
12. Navura	1.5	0.53	0.35	3.16	26.00	61.3	43.8	5.76
LSD_{95}		0.4	0.2	5.7	8.8	11.2	2.9	3.2

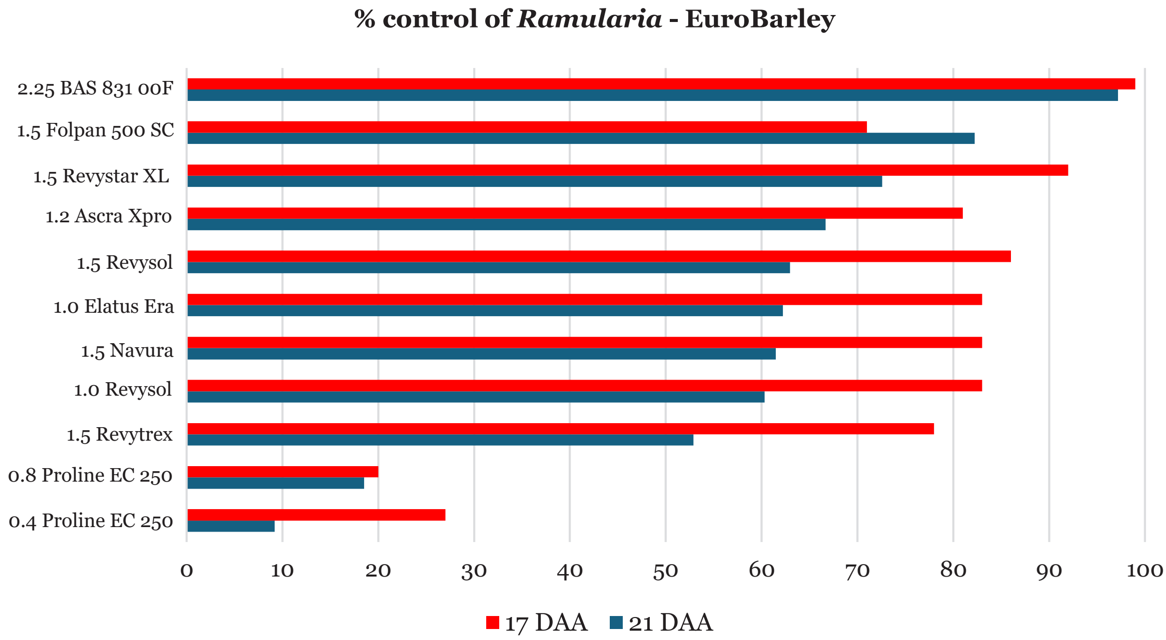


Figure 2. Per cent control of *Ramularia* leaf spot at two timings in spring barley. Leaves were assessed at GS 77. Attack in untreated plots: 19% *Ramularia*, 17 days after application (DAA) and 65%, 21 DAA (24386).

Untreated

1.5 Revysol

0.8 Proline EC 250

The trial in Ireland had a severe infection, while the German trial only had a moderate level of infection. The Scottish trial had very low levels of attack and did not provide usable data (Table 4). In all three countries, BAS 831 00F gave the best control of Ramularia leaf spot (Figure 3). In Germany, also the co-formulations Elatus Era, Ascra Xpro, Revytrex and Revystar XL gave good control (>75%). In all three countries, Revysol performed better than Proline EC 250, and slight dose responses were seen for both products.

Revysol and Proline EC 250 both showed a clear dose response in the yield increases (Figure 4). The treatment with BAS 831 00F gave by far the best yield increase across the three trials, while Proline EC 250 showed the lowest yield increases.

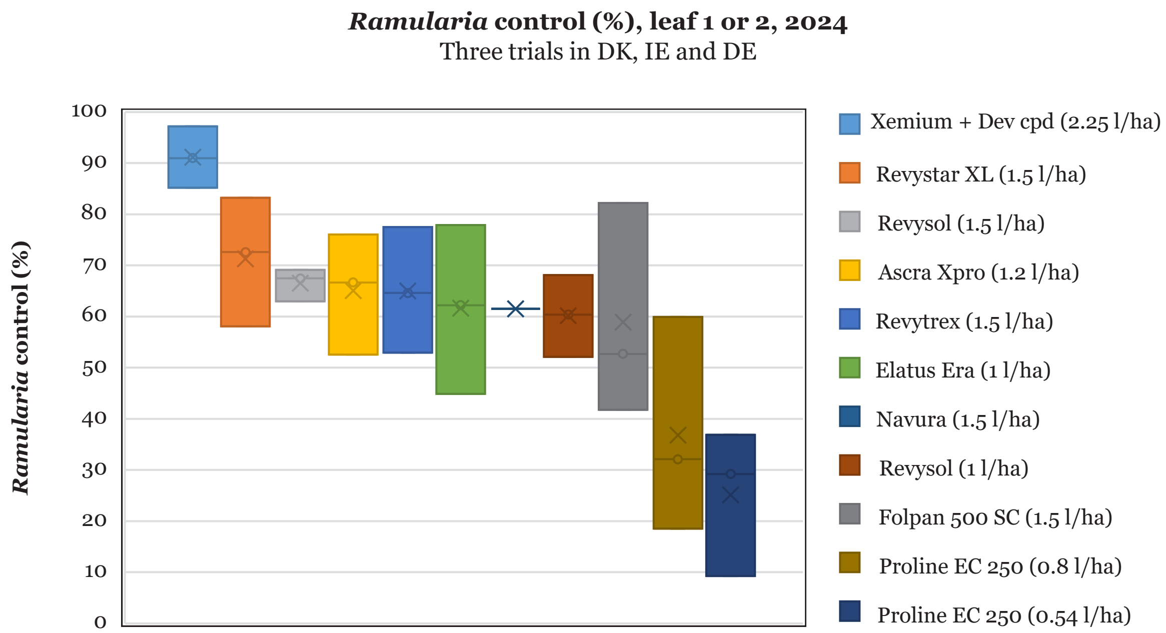


Figure 3. Control of *Ramularia* on first and second leaves. Three trials in Denmark, Ireland and Germany. Assessments were carried out at GS 65-75, 15-22 DAA. Treatment with Navura was only included in Denmark.

Table 4. Control (%) and severity (% in untreated) of *Ramularia* in Denmark, Ireland, Scotland and Germany in 2024, GS 65-78, DAA 15-22, leaf 1 or 2. Control effects are summarised as percentage reduction of attack relative to untreated plots. Colours signify ranking of treatment effects within trials. Green: highest rated effect. Yellow: medium rated effect. Orange: lowest rated effect. Red: disease severity in untreated. Dosages are presented in l/ha.

Control (%), *Ramularia*, leaf 1 or 2, 2024				Untr.	Revysol		Proline EC 250		Folpan 500 SC	Elatus Era	Ascra Xpro	Revy-trex	Revystar XL	Xemium + Dev cpd	Navura
Trial	Ctry.	GS	DAA	-	100	150	133	200	750	75 + 150	98 + 98 + 200	100 + 100	100 + 2400	90 + 90	50 + 100
24386-1	DK	75	21	67.5	60	63	9	19	82	62	67	53	73	97	61
24386-2	IE	65	15	74.9	68	67	29	32	53	45	53	65	58	85	-
24386-3	UK-SCT	78	30	6.3	8	0	24	0	0	16	37	0	29	29	-
24386-4	DE	71	22	12.8	52	69	37	60	42	78	76	77	83	91	-
Avg. control (%), minus trial 3				51.7	60.2	66.5	25.1	36.8	58.9	61.7	65.1	65.0	71.3	91.1	61.5

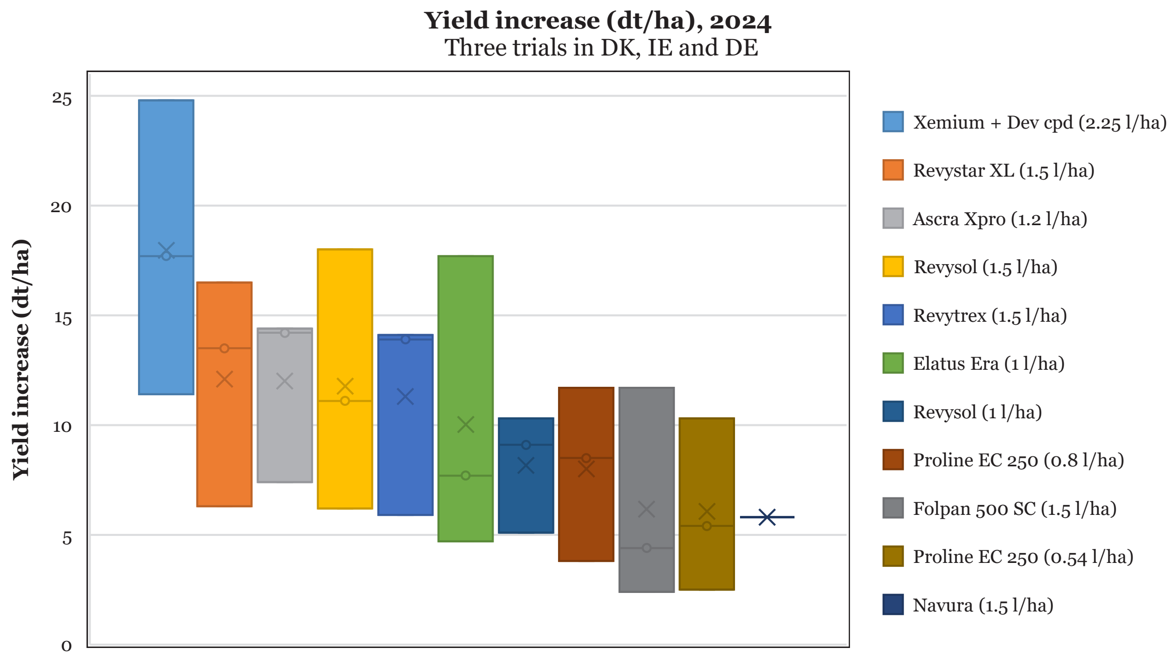


Figure 4. Yield increases (dt/ha) of three trials in Denmark, Ireland and Germany. The Scottish trial was not included due to the lack of statistically significant increases.

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Ramularia leaf spot in barley.

IV Control strategies in different cereal cultivars

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Control strategies in different winter wheat cultivars

One split-plot trial was established at AU Flakkebjerg and included eight different control strategies, which were compared in six different winter wheat cultivars, reflecting some of the most commonly grown cultivars in Denmark. The cultivar mixture included only resistant cultivars which have different levels of resistance against yellow rust, mildew and *Septoria* (Kvium, Informer and Pondus). LG Skyscraper was included to include a cultivar with a low degree of resistance. The trial was organised as a split-plot trial with three replicates. One of the treatments included the use of the decision support system Crop Protection Online (CPO) to evaluate the need for treatments based on rain, humidity and the resistance of a cultivar. The trial also included a treatment based on treating the crop when the qPCR method showed signs of *Septoria* DNA (>5 pg *Septoria* DNA/mg plant tissue). Treatment 6 recommended alternative chemistry in combination with the thresholds in CPO. The project was financed by the income from user fees of CPO, the Danish Environmental Protection Agency's pesticide research programme, the EU project ADOPT-IPM and from Bayer Crop Science supporting the qPCR activity.

The following strategies were tested:

1. Untreated
2. 0.75 l/ha Balaya (GS 37-39)
3. 0.75 l/ha Balaya / 0.5 l/ha Propulse SE 250 + 0.25 l/ha Folicur Xpert (GS 37-39 / GS 55-61)
4. 3.0 l/ha Thiopron / 3.0 l/ha Thiopron (GS 37-39 / GS 55-61)
5. 0.3 l/ha Balaya + 3.0 l/ha Thiopron / 0.25 l/ha Propulse SE 250 + 0.125 l/ha Folicur Xpert (GS 37-39 / GS 55-61)
6. Treatments according to CPO, using alternative chemistry and biologicals.
7. Treatments according to qPCR (using 0.5 l/ha Propulse SE 250 + 0.25 l/ha Folicur Xpert)
8. Treatments according to CPO (using 0.5 l/ha Propulse SE 250 + 0.25 l/ha Folicur Xpert)

Moderate levels of *Septoria* infections developed in the trial, and later also significant infections of brown rust were seen, particularly in Kvium. Registration of rain events ensured that all cultivars were treated using the treatment thresholds in CPO. The CPO treatments took place in all cultivars on 1 June, using 0.5 l/ha Propulse SE 250 + 0.25 l/ha Folicur Xpert.

Using qPCR as the method to decide when to spray, a threshold level of 5 pg *Septoria* DNA/mg plant tissue was used, giving a treatment in Informer on 1 June (GS 55-59) and a treatment in the other cultivars (minus the mixture) on 11 June (GS 65-69). For these treatments, 0.5 l/ha Propulse SE 250 + 0.25 l/ha Folicur Xpert was used. The readings from the qPCR testing are given in Table 1. Treatment 6, using alternative chemistry in combination with CPO, was treated twice with Thiopron at GS 32 and GS 51 followed by Lalstop G46 WG at GS 55-61.

Initially, LG Skyscraper had most infection of *Septoria* – but later in the season Pondus was the cultivar most severely hit on the flag leaf. Kvium and Pondus were most severely infected by brown rust (Table 3). The three standard chemical treatments (tr. 2, 3 and 5) gave very similar control of *Septoria* (80-90%) and brown rust (Figures 1 and 2; Table 3). The treatment using

Thiopron twice (tr. 4) gave approx. 40% control, and so did the qPCR treatments, which suffered from late timing. The final qPCR readings are shown in Figure 3 and show the best reduction in the infection level in Informer, which was treated earlier than the other cultivars. CPO gave approx. 60% control of *Septoria*, which also was below the levels from the chemical reference treatments. The two applications using Thiopron gave least control of both *Septoria* and brown rust, and the solution with alternative chemistry (tr. 6) gave control in line with this treatment.

Table 1. Results from the qPCR analysis in the cultivar trial. In this trial, we used a threshold of 5 pg *Septoria* DNA/mg plant tissue on the lower sampled leaf before releasing treatments. Two leaves – the upper and the lower – were sampled per timing. The lower leaves generally had higher levels of DNA and were used as indicator. Yellow colouring indicates values above the threshold fixed at 5.

	24-04-2024	07-05-2024	15-05-2024	27-05-2024	06-06-2024
GS	30	31	37	55	57
Cultivar mixture		1	3	4	5
LG Skyscraper	0.1	1	3	5	45
Kvium	0.1	0.9	0.1	0.4	9
Pondus	2	0.6	5	2	23
Informer	0.1	0.7	0.1	11	15

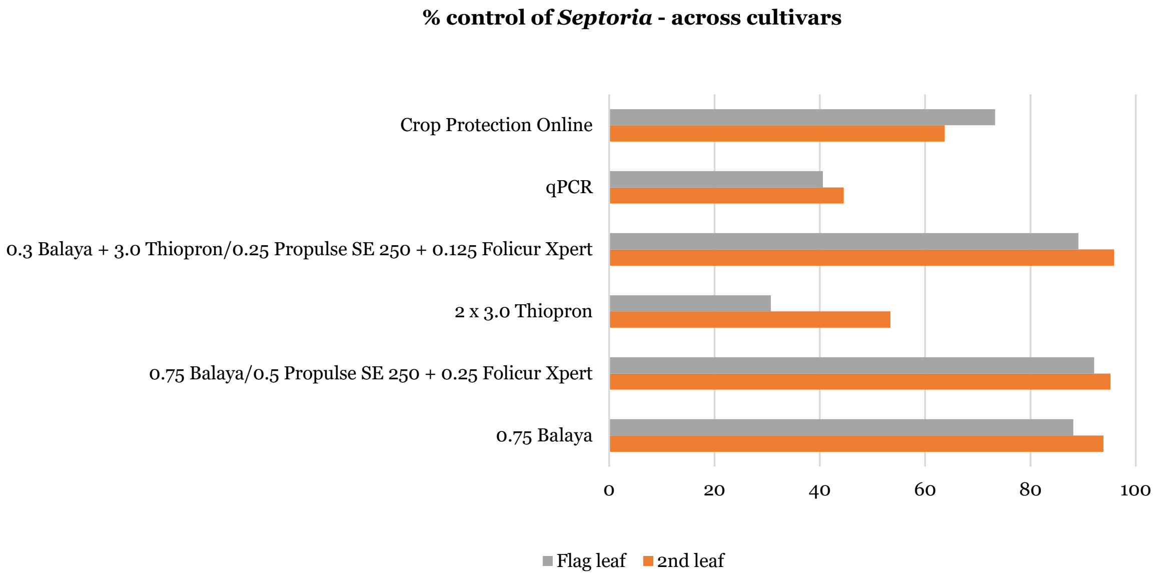

Figure 1. Control of *Septoria* assessed on the flag leaf and the second leaf at GS 75. All treatments reduced the attack. Data are based on a summary across all cultivars.

Yield levels were generally moderate to high, and yield responses following fungicide applications were significantly increased, varying between 15 dt/ha and 20 dt/ha (Figure 4; Table 2). Kvium had the lowest yield in untreated and the highest yield increases from fungicide treatments because of severe brown rust infections. Double applications with Thiopron gave moderate disease control and very low yield increases. Double applications with the higher chemical rates (tr. 3) gave the best gross yield increase. However, a single application with Balaya (tr. 2) and reduced rates of Balaya and Propulse SE 250 (tr. 5) gave net yields similar to double applications using higher rates of Balaya and Propulse SE 250 (tr. 3) (Figure 4; Table 3).

The threshold-based solutions fell behind in yield responses compared with the chemical references. The qPCR treatments suffered most from a late treatment, but also CPO did not give satisfactory responses due to a combination of late timing and Balaya not being allowed at the later timing (>GS 40), which meant that a less effective solution was applied. If the qPCR threshold had been lowered to for instance “2”, an earlier timing would have been applied (Table 1) in all cultivars with the exception of Kvium. Kvium ended up suffering a lot from brown rust, which meant that another threshold system than the qPCR *Septoria* system should have been included.

The cultivar mixture consisting of equal parts of Pondus, Kvium and Informer gave a clear reduction in disease levels for both *Septoria* and brown rust when compared with average infection levels in the three solo cultivars (Table 2). In untreated plots, the reduction of *Septoria* varied between 17% and 38% when the attack in the mixture was compared with the average level of the infection in the three solo cultivars. The reduction on brown rust was also very significant (58%). In addition, the effects on yield and thousand grain weight showed a benefit from mixing cultivars.

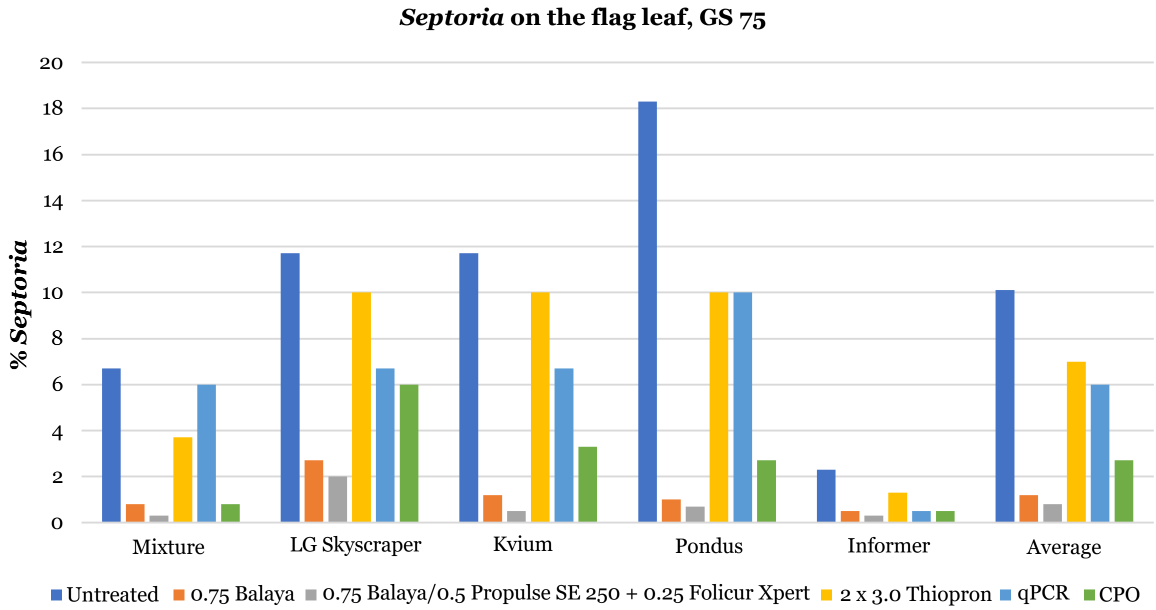

Figure 2. Attack of *Septoria* assessed on the flag leaf at GS 75. All treatments reduced the attack; however, to varying degrees.

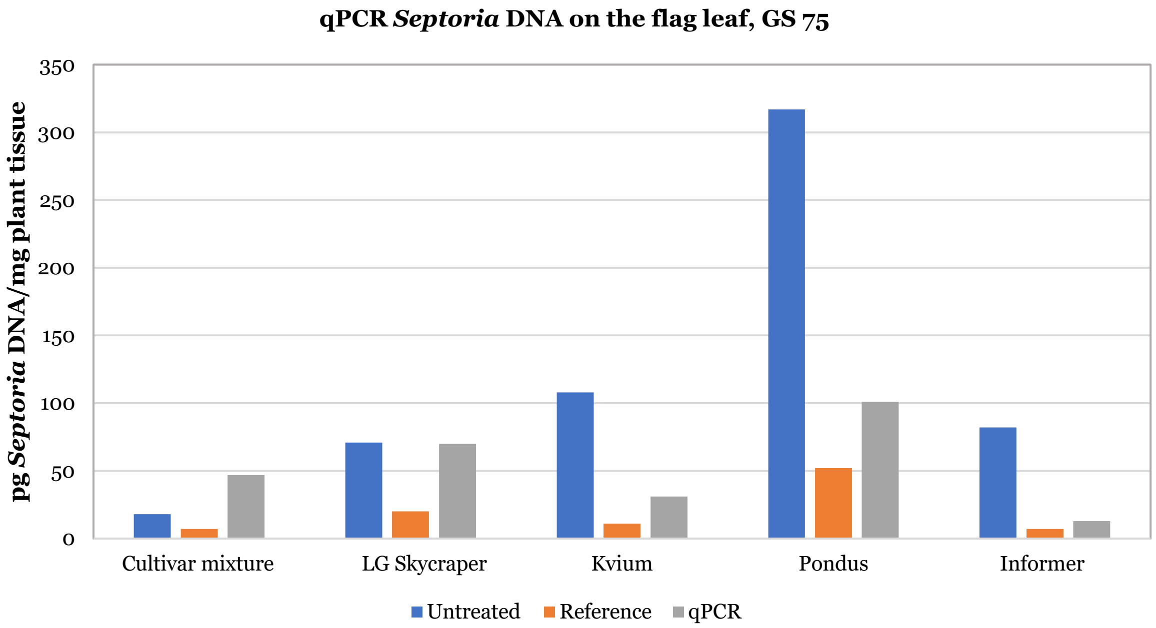

Figure 3. Final qPCR readings from the trial including data from untreated, reference treatment (tr. 3) and qPCR-treated plots.

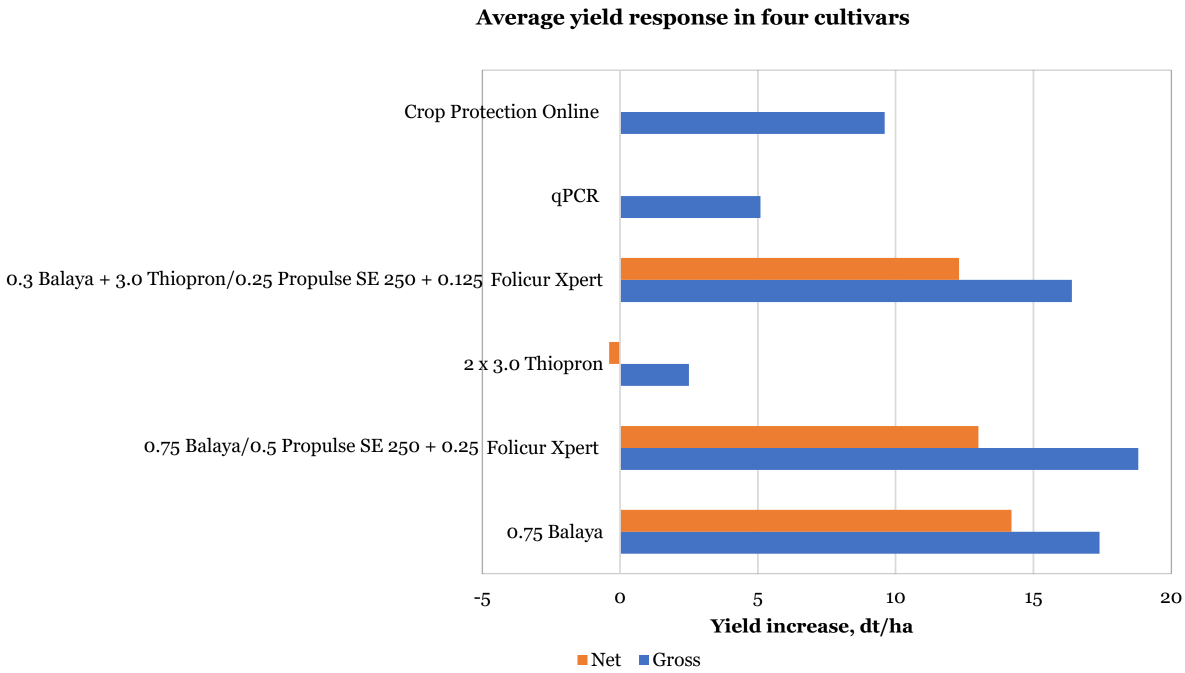

Figure 4. Yield increases and net yields following different treatments in four different cultivars and a cultivar mixture. Data from split-plot trial at AU Flakkebjerg.

Table 2. Benefit from growing the mixtures on disease control, yield responses and thousand grain weight – data from untreated plots.

	% *Septoria*, flag leaf	% *Septoria*, 2nd leaf	% brown rust, flag leaf	Yield, dt/ha	TGW, g
Cultivar mixture	6.7	21.5	3.3	80.4	45.4
Kvium	11.7	25.2	15	70.5	42
Pondus	18.3	31.1	6	74.3	43
Informer	2.3	21.5	2.5	78.4	47.4
Average of three cultivars	10.8	25.9	7.8	74.4	44.1
% improvement	38%	17%	58%	8%	3%

Table 3. Per cent control of *Septoria* and brown rust, green leaf area (GLA) and yield responses. One trial at Velas in Jutland and one trial at AU Flakkebjerg with five winter wheat cultivars, using eight different fungicide treatments (24350). (Continues on the next page).

Cultivars	% *Septoria*, leaf 1, GS 75								% *Septoria*, leaf 2, GS 75							
	Untr.	0.75 Balaya	0.75 Balaya / 0.5 Propulse SE 250 + 0.25 Folicur Xpert	3.0 Thiopron / 3.0 Thiopron	0.3 Balaya + 3.0 Thiopron / 0.25 Propulse SE 250 + 0.125 Folicur Xpert	CPO bio	qPCR	CPO chemistry	Untr.	0.75 Balaya	0.75 Balaya / 0.5 Propulse SE 250 + 0.25 Folicur Xpert	3.0 Thiopron / 3.0 Thiopron	0.3 Balaya + 3.0 Thiopron / 0.25 Propulse SE 250 + 0.125 Folicur Xpert	CPO bio	qPCR	CPO chemistry
Cultivar mixture	6.7	0.8	0.3	3.7	0.5	2.7	6.0	0.8	21.5	3.6	4.2	15.9	4.2	20.0	23.2	16.5
LG Skyscraper	11.7	2.7	2.0	10.0	2.0	8.3	6.7	6.0	51.3	21.5	21.5	33.0	18.2	37.5	44.8	34.8
Kvium	11.7	1.2	0.5	10.0	1.2	11.7	6.7	3.3	25.2	4.2	4.2	18.2	3.6	18.2	19.6	13.1
Pondus	18.3	1.0	0.7	10.0	1.2	11.7	10	2.7	31.1	5.9	4.2	15.9	3.6	19.6	23.2	16.5
Informer	2.3	0.5	0.3	1.3	0.5	1.3	0.5	0.5	21.5	5.8	3.6	11.3	4.2	20.0	7.3	85
Average	10.1	1.2	0.8	7.0	1.1	7.1	6.0	2.7	30.1	8.2	7.5	18.9	6.8	23.1	23.6	17.9
LSD_{95}	5.5								5.1							

Cultivars	% brown rust 1, GS 73							
	Untr.	0.75 Balaya	0.75 Balaya / 0.5 Propulse SE 250 + 0.25 Folicur Xpert	3.0 Thiopron / 3.0 Thiopron	0.3 Balaya + 3.0 Thiopron / 0.25 Propulse SE 250 + 0.125 Folicur Xpert	CPO bio	qPCR	CPO chemistry
Cultivar mixture	3.3	0.2	0.0	3.3	0.1	2.7	4.3	0.6
LG Skyscraper	0.2	0.0	0.0	1.8	0.0	1.2	1.2	0.5
Kvium	15.0	0.7	0.2	1.0	1.8	15.0	2.7	2.0
Pondus	6.0	0.8	0.1	4.0	0.8	3.0	3.3	2.7
Informer	2.5	0.0	0.0	1.1	0.0	2.2	0.0	0.0
Average	5.4	0.3	0.1	5.0	0.5	4.8	2.3	1.2
LSD_{95}	2.0							

Table 3. Per cent control of *Septoria* and brown rust, green leaf area (GLA) and yield responses. One trial at Velas in Jutland and one trial at AU Flakkebjerg with five winter wheat cultivars, using eight different fungicide treatments (24350). (Continued)

Cultivars	% green leaf area, leaf 2, GS 71-73								% green leaf area, leaf 1, GS 81-83							
	Untr.	0.75 Balaya	0.75 Balaya / 0.5 Propulse SE 250 + 0.25 Folicur Xpert	3.0 Thiopron / 3.0 Thiopron	0.3 Balaya + 3.0 Thiopron / 0.25 Propulse SE 250 + 0.125 Folicur Xpert	CPO bio	qPCR	CPO chemistry	Untr.	0.75 Balaya	0.75 Balaya / 0.5 Propulse SE 250 + 0.25 Folicur Xpert	3.0 Thiopron / 3.0 Thiopron	0.3 Balaya + 3.0 Thiopron / 0.25 Propulse SE 250 + 0.125 Folicur Xpert	CPO bio	qPCR	CPO chemistry
Cultivar mixture	41.7	88.3	91.7	40.0	90.0	46.7	33.3	81.7	43.3	56.7	35.3	41.7	66.7	45.0	35.0	76.7
LG Skyscraper	16.7	60.0	56.7	26.7	58.3	25.0	26.7	31.7	20.0	41.7	45.0	21.7	50.0	13.3	26.7	25.0
Kvium	20.0	86.7	90.0	20.0	83.3	20.0	38.3	46.7	13.3	66.7	76.7	8.3	73.3	16.7	28.3	46.7
Pondus	21.7	83.3	90.0	41.7	85.0	30.0	41.7	75.0	23.3	43.3	73.3	26.7	56.7	38.3	46.7	41.7
Informer	58.3	90.0	91.7	73.3	90.0	68.3	86.7	85.0	45.0	66.7	90.0	48.3	90.0	41.7	78.3	76.7
Average	31.7	81.7	84.0	40.3	81.3	38.0	45.3	64.0	29.0	55.0	64.1	29.3	67.3	31.0	43.0	53.4
LSD_{95}	12.7								22.0							

Cultivars	TGW (g)							
	Untr.	0.75 Balaya	0.75 Balaya / 0.5 Propulse SE 250 + 0.25 Folicur Xpert	3.0 Thiopron / 3.0 Thiopron	0.3 Balaya + 3.0 Thiopron / 0.25 Propulse SE 250 + 0.125 Folicur Xpert	CPO bio	qPCR	CPO chemistry
Cultivar mixture	45.4	52.2	53.7	44.2	51.7	44.7	42.0	48.5
LG Skyscraper	46.7	49.7	52.6	45.7	50.5	43.7	45.2	45.6
Kvium	42.0	51.8	52.0	42.4	51.1	40.5	45.2	46.8
Pondus	43.0	46.4	47.9	40.5	45.3	41.1	43.5	45.3
Informer	47.4	53.1	52.9	48.2	53.6	48.9	51.2	51.6
Average	44.9	50.6	51.8	44.2	50.4	43.8	45.4	47.6
LSD_{95}	3.0							

Table 3. Per cent control of *Septoria* and brown rust, green leaf area (GLA) and yield responses. One trial at Velas in Jutland and one trial at AU Flakkebjerg with five winter wheat cultivars, using eight different fungicide treatments (24350). (Continued).

Cultivars	Yield & yield increase, dt/ha								Net increase, dt/ha			
	Untr.	0.75 Balaya	0.75 Balaya / 0.5 Propulse SE 250 + 0.25 Folicur Xpert	3.0 Thiopron / 3.0 Thiopron	0.3 Balaya + 3.0 Thiopron / 0.25 Propulse SE 250 + 0.125 Folicur Xpert	CPO bio	qPCR	CPO chemistry	0.75 Balaya	0.75 Balaya / 0.5 Propulse SE 250 + 0.25 Folicur Xpert	3.0 Thiopron / 3.0 Thiopron	0.3 Balaya + 3.0 Thiopron / 0.25 Propulse SE 250 + 0.125 Folicur Xpert
Cultivar mixture	80.4	17.5	15.9	1.0	13.5	2.8	-3.2	5.8	14.3	10.5	-2.0	9.4
LG Skyscraper	82	13.3	14.9	2.9	12.6	2.4	2.2	4.5	10.1	9.5	-0.1	8.5
Kvium	70.5	25.9	28.4	2.7	24.6	5.3	10	17.6	22.7	23.0	-0.3	20.5
Pondus	74.3	16.2	19.9	3.1	15.8	4.2	4.8	8.6	13.0	14.5	0.1	11.7
Informer	78.4	14.1	15.0	2.7	15.3	2.9	11.5	11.2	10.9	9.6	-0.3	11.2
Average	77.1	17.4	18.8	2.5	16.4	3.5	5.1	9.5	14.2	13.4	-0.5	12.3
LSD_{95}				6.7								

Untr. = Untreated; 0.75 l/ha Balaya, GS 37-39 (costs = 3.2 dt/ha); 0.75 l/ha Balaya, GS 37-39 / 0.5 l/ha Propulse SE 250 + 0.25 l/ha Folicur Xpert, GS 55-61 (costs = 5.8 dt/ha); 3.0 l/ha Thiopron, GS 37-39 / 3.0 l/ha Thiopron, GS 55-61 (costs = 2.9 dt/ha); 0.3 l/ha Balaya + 3.0 l/ha Thiopron, GS 37-39 / 0.25 Propulse SE 250 + 0.125 l/ha Folicur Xpert, GS 55-61 (costs = 4.1 dt/ha).

Control of strategies in different spring barley cultivars

Five different control strategies including untreated and Crop Protection Online (CPO) were tested in four spring barley cultivars. Three of the cultivars were established both as solo cultivars (Skyway, Laureate, RGT Planet) and as a mixture of the three cultivars. The trial was located at AU Flakkebjerg. The trial was sown on 2 May, which was late due to a very wet spring.

The tested strategies:

1. Untreated
2. 0.5 l/ha Pictor Active + 0.25 l/ha Proline EC 250 (GS 37-39)
3. 0.25 l/ha Propulse SE 250 + 0.3 l/ha Comet Pro (GS 37-39)
4. 0.25 l/ha Pictor Active / 0.35 l/ha Propulse SE 250 + 0.3 l/ha Comet Pro (GS 32 / GS 51)
5. Treatments according to CPO

The trial developed a moderate attack of net blotch and a very severe attack of brown rust. There were clear and statistically significant differences between the treatments and clear differences between untreated and treated plots (Table 4). When assessed at GS 47 and 69, rust was, however, better controlled from single treatments at GS 37-39 (treatments 2 and 3) compared with double applications (treatment 4). Only later was a benefit from the double applications seen on per cent green leaf area.

A severe attack of *Ramularia* came late in the season, and only moderate control was provided from treatments 2 and 3, while treatment 4 with two applications gave 74-84% control.

CPO recommended one treatment in all cultivars based on the attack of brown rust. Skyway was treated on 21 June at GS 49, using 0.3 l/ha Propulse SE 250 + 0.25 l/ha Comet Pro. Laureate, RGT Planet and the cultivar mixture were treated on 26 June at GS 55, also using 0.3 l/ha Propulse SE 250 + 0.25 l/ha Comet Pro.

Yields in untreated were low and ranged from 38 dt/ha to 42 dt/ha. Yield increases on the other hand were very high and statistically significant because of the severe rust attack. Treatment 4 with double applications resulted in the highest yield increase, reaching 24 dt/ha on average (Figure 5; Table 4). CPO gave only moderate control and a lower yield response compared with treatments 2 and 4. This was due to a delayed timing of application.

Table 4. Control of diseases in spring barley, green leaf area (GLA) and yield responses from one trial in four different spring barley cultivars, using four different strategies. Untr. = untreated. CPO = Crop Protection Online (23352-1). (Continues on the next page).

	% brown rust, leaf 3, GS 47					% brown rust, leaf 2, GS 69				
	Untr.	0.5 Pictor Active + 0.25 Proline EC 250	0.25 Propulse SE 250 + 0.3 Comet Pro	0.25 Pictor Active / 0.35 Propulse SE 250 + 0.3 Comet Pro	CPO	Untr.	0.5 Pictor Active + 0.25 Proline EC 250	0.25 Propulse SE 250 + 0.3 Comet Pro	0.25 Pictor Active / 0.35 Propulse SE 250 + 0.3 Comet Pro	CPO
Skyway	18.2	5.0	5.0	5.0	15.0	76.5	3.8	5.9	20.2	17.2
Laureate	6.9	2.3	3.8	3.8	7.3	38.4	4.8	4.8	10.0	22.9
RGT Planet	15.5	3.8	5.0	3.8	12.2	65.4	5.0	2.8	18.2	23.0
Cultivar mix	10.7	5.0	5.0	5.0	9.9	63.2	3.8	6.3	14.5	25.2
LSD_{95}	7.4					3.3				
Average	12.8	4.0	4.7	4.4	11.1	60.9	4.4	5.0	15.7	22.1

	% net blotch, leaf 3, GS 69					% *Ramularia*, leaf 2, GS 75				
	Untr.	0.5 Pictor Active + 0.25 Proline EC 250	0.25 Propulse SE 250 + 0.3 Comet Pro	0.25 Pictor Active / 0.35 Propulse SE 250 + 0.3 Comet Pro	CPO	Untr.	0.5 Pictor Active + 0.25 Proline EC 250	0.25 Propulse SE 250 + 0.3 Comet Pro	0.25 Pictor Active / 0.35 Propulse SE 250 + 0.3 Comet Pro	CPO
Skyway	11.7	7.7	10	8.3	10.	63.3	33.3	35	16.7	30
Laureate	2.7	1.0	0.3	0.7	1.3	36.7	18.3	16	5	16.7
RGT Planet	13.3	10	5.3	10	13.3	50	26.7	28.3	18.3	31.7
Cultivar mix	11.0	4.7	11	7.7	8.0	60	18.3	28.3	15	26.7
LSD_{95}	5.0					15				
Average	9.7	5.9	6.7	6.7	8.2	52.5	24.2	26.9	13.8	26.3

Cultivars	% GLA leaf 2, GS 83					TGW, g/1000				
	Untr.	0.5 Pictor Active + 0.25 Proline EC 250	0.25 Propulse SE 250 + 0.3 Comet Pro	0.25 Pictor Active / 0.35 Propulse SE 250 + 0.3 Comet Pro	CPO	Untr.	0.5 Pictor Active + 0.25 Proline EC 250	0.25 Propulse SE 250 + 0.3 Comet Pro	0.25 Pictor Active / 0.35 Propulse SE 250 + 0.3 Comet Pro	CPO
Skyway	0	36.7	26.7	50.0	18.3	34	40.2	39.0	41.1	39.9
Laureate	10	46.7	36.7	63.3	36.7	34.1	41.1	41.9	43.9	38.1
RGT Planet	0	43.3	35.0	50	13.3	34.0	42.8	42.3	44.8	40.1
Cultivar mix	0	63.3	36.7	63.3	21.7	36.0	44.6	39.5	44.4	40.2
LSD_{95}	19.8					4.1				
Average	2.5	47.5	33.8	56.7	22.5	34.5	42.2	40.7	43.6	39.6

Table 4. Control of diseases in spring barley, green leaf area (GLA) and yield responses from one trial in four different spring barley cultivars, using four different strategies. Untr. = untreated. CPO = Crop Protection Online (23352-1). (Continued).

Cultivars	Yield (untreated) & yield increase (%), dt/ha					Net increase, dt/ha			
	Untr.	0.5 Pictor Active + 0.25 Proline EC 250	0.25 Propulse SE 250 + 0.3 Comet Pro	0.25 Pictor Active / 0.35 Propulse SE 250 + 0.3 Comet Pro	CPO	0.5 Pictor Active + 0.25 Proline EC 250	0.25 Propulse SE 250 + 0.3 Comet Pro	0.25 Pictor Active / 0.35 Propulse SE 250 + 0.3 Comet Pro	CPO
Skyway	37.93	21.9	18	29.2	19.91	19.0	15.9	25.2	17.8
Laureate	41.16	15.7	13.1	22.0	12.6	12.8	11.0	18.0	10.5
RGT Planet	41.3	18.0	17.8	24.6	11.5	15.1	15.7	20.6	9.4
Cultivar mix	41.6	20.8	14.9	20	11.3	17.9	12.8	16.0	9.2
LSD_{95}			6.9						
Average	40.5	19.1	15.95	23.95	13.8	16.2	13.9	19.95	11.7

Untr. = Untreated; 0.5 l/ha Pictor Active + 0.25 l/ha Proline EC 250, GS 37-39 (costs = 2.9 dt/ha); 0.25 l/ha Propulse SE 250 + 0.3 l/ha Comet Pro, GS 37-39 (costs = 2.1 dt/ha); 0.25 l/ha Pictor Active, GS 32 / 0.35 l/ha Propulse SE 250 + 0.3 l/ha Comet Pro, GS 51 (costs = 4.0 dt/ha); CPO = Crop Protection Online (costs = 2.1 dt/ha).

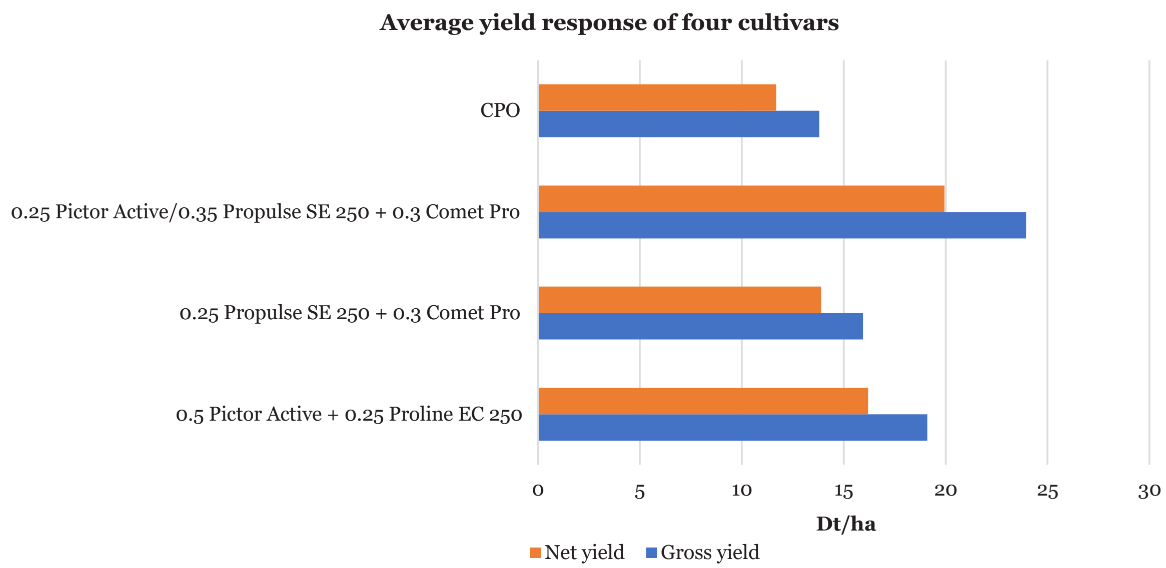

Figure 5. Average yield increases and net yields in spring barley from different treatments. Average of four different cultivars. Data from split-plot trial at AU Flakkebjerg (24352).

V Fungicide resistance-related investigations

Niels Matzen, Brittany Deanna Beck, Birgitte Boyer Frederiksen, Anja Maribo Lassen & Lise Nistrup Jørgensen

Fungicide resistance in *Zymoseptoria tritici* in Denmark and Sweden

The development of fungicide resistance in Danish and Swedish *Z. tritici* populations is monitored every year in a collaboration between Aarhus University (AU), SEGES, local advisers and several agro-chemical companies in Denmark and Jordbruksverket in Sweden. Leaf samples with clear symptoms of Septoria tritici blotch are collected around growth stages (GS) 73-77 and forwarded for analysis at AU-AGRO. The sensitivity to prothioconazole, which was tested in the form of the metabolites prothioconazole-desthio (PTH-D) and fluxapyroxad (FLX), was analysed for 119 isolates from 18 Danish samples and 187 isolates from 30 Swedish samples in 2024 (Tables 1 and 3). The disease pressure of Septoria tritici blotch was generally moderate to high in 2024. The aim was to collect 10 isolates from each location, which was not always possible. Due to several rain events, many pycnidia had already been released at the time of sampling – making it difficult to isolate a sufficient number of spores.

The *Z. tritici* isolates were collected by scraping off six-day-old spores from individual pycnidia, which were transferred into Milli-Q water, and the spore suspensions were then homogenised and adjusted to a spore concentration of 2.4 x 104 spores ml-1. The sensitivity testing was then carried out on microtitre plates with technical duplicates for each isolate. The isolates IPO323 and OP15.1 were used as sensitive references. The active ingredients prothioconazole-desthio and fluxapyroxad were dissolved in 80% ethanol. These fungicide stock solutions were mixed with 2 x potato dextrose broth (PDB). The PDB fungicide solutions were added to the microtitre plates with the final concentrations of (mg/l): 6.0, 2.0, 0.67, 0.22, 0.074, 0.025, 0.008 and 0 (prothioconazole-desthio) and 9.0, 3.0, 1.0, 0.33, 0.11, 0.04, 0.01 and 0 (fluxapyroxad). A total of 100 µl spore suspension and 100 µl PDB fungicide solution was added to the 96-deep well microtitre plates. The plates were then wrapped in tinfoil and incubated at 22°C for 6 days in a dark room. The plates were analysed using an ELISA reader at 620 nm. The fungicide sensitivity was found by determining the fungicide concentration, which inhibited *Z. tritici* growth by 50% (EC_{50}). This value was determined by a non-linear regression using GraphPad Prism (Version 9.5.0 (730), November 9, 2022). Resistance factors were calculated by dividing EC_{50} values of isolates by those of the sensitive reference IPO323, which were 0.01 for prothioconazole-desthio and 0.15 for fluxapyroxad.

The results presented here are a continuation of resistance monitoring for prothioconazole and fluxapyroxad, which has been carried out in Denmark since 2016 and 2018, respectively, and in Sweden since 2017 and 2018, respectively (Heick et al., 2023).

Results – Denmark

The severity of Septoria tritici blotch in Denmark was moderate in 2024. Twenty-six samples were collected from different sites and fields, but it was only possible to isolate spores from 18 sites. In several cases, only few isolates were collected as *Septoria* infections were limited or pycnidia were empty of spores.

For prothioconazole-desthio, the average EC_{50} value in Denmark for 2024 was 0.27 ppm, indicating a result similar to previous years: 2023 (avg. 0.44 ppm), 2022 (avg. 0.30 ppm), 2021 (avg. 0.32 ppm) and 2020 (avg. 0.44 ppm) (Figure 1; Table 2). The resistance factor was on average 24 in 2024, which is at the moderate end compared with previous years' findings with a range between 30 and 44. The sensitivity varied widely among sites, with resistance factors ranging from 3 to 115 (Table 1). These findings suggest that, overall, the sensitivity of the Danish *Z. tritici* population has shifted but also stabilised at a reduced sensitivity level. In 2021 and 2024, the *Septoria* infection levels were high and the EC_{50} values a little lower (0.27-0.32 ppm) than in the years 2020 and 2023 with lower severity and higher EC_{50} values (0.44 ppm). This indicates that the selection pressure might be a bit more severe in years with low disease pressure than in years with more severe infections.

Similarly, a decreased sensitivity to fluxapyroxad in terms of increased EC_{50} was seen for Danish *Z. tritici* in 2024 (avg. 0.66 ppm) compared to the results of 2022 (avg. 0.46 ppm) and 2021 (avg. 0.44 ppm) (Figure 2; Table 2). Despite the observed progressively decreased sensitivity since 2018, the resistance factor is still generally at a low level, indicating that *Z. tritici* is still sensitive to fluxapyroxad and other succinate dehydrogenase inhibitors (SDHIs).

A subset consisting of one isolate per location was analysed for its sensitivity to mefentrifluconazole. The EC_{50} values were similar to those seen in the previous years (Figure 3).

In summary, the sensitivity of Danish *Z. tritici* population towards the three active ingredients did not show a new overall shift compared with more recent years.

Table 1. Mean EC_{50} values and resistance factors (RF) for prothioconazole-desthio (PTH-D) and fluxapyroxad (FLX) for 119 *Z. tritici* isolates from 18 Danish samples collected across Denmark in 2024.

Location		EC_{50} (ppm)						Number of isolates
		PTH-D	RF	Range	FLX	RF	Range	
24-ZT-DK-01	Flakkebjerg	0.15	15	0.03-0.39	0.11	1	0.01-0.90	10
24-ZT-DK-02	Agerskov	0.22	22	0.01-1.11	0.07	0	0.03-0.22	10
24-ZT-DK-03	Hyllested	0.28	28	0.02-0.79	0.06	0	0.05-0.07	3
24-ZT-DK-04	Ultang	0.21	21	0.02-0.71	0.10	1	0.03-0.15	10
24-ZT-DK-05	Ultang	0.17	17	0.01-0.83	0.22	1	0.15-0.27	9
24-ZT-DK-06	Rønde	1.15	115	0.01-6.00	0.31	2	0.03-0.42	7
24-ZT-DK-07	Rønde	0.12	12	0.04-0.26	0.55	4	0.44-0.68	8
24-ZT-DK-08	Rønde	0.33	33	0.03-0.71	0.97	6	0.77-1.39	4
24-ZT-DK-09	Holeby	0.33	33	0.02-1.16	0.83	6	0.03-1.20	4
24-ZT-DK-10	Holeby	0.23	23	0.03-0.5	1.52	10	0.04-2.22	10
24-ZT-DK-11	Skamby	0.26	26	0.01-1.04	2.32	15	0.13-9.00	10
24-ZT-DK-12	Skamby	0.31	31	0.01-1.94	0.87	6	0.01-2.83	9
24-ZT-DK-14	Aalborg	0.03	3	0.03-0.03	0.05	0	0.05-0.05	1
24-ZT-DK-15	Vester	0.17	17	0.04-0.53	1.32	9	0.07-4.95	8
24-ZT-DK-16	Ringsted	0.03	3	0.03-0.03	0.04	0	0.04-0.04	1
24-ZT-DK-18	Vojens	0.27	27	0.02-1.17	0.67	4	0.02-1.88	8
24-ZT-DK-19	Vojens	0.03	3	0.03-0.03	0.05	0	0.05-0.05	1
24-ZT-DK-20	Vojens	0.08	8	0.01-0.24	0.61	4	0.01-1.37	6

Table 2. Summary of mean EC_{50} (ppm) values and resistance factors (RF) for prothioconazole-desthio and fluxapyroxad assessed for *Z. tritici* in Denmark from 2016 to 2024. The total number of isolates tested are given in brackets.

Year	EC_{50} (ppm)			
	Prothio.-desthio	RF	Fluxapyroxad	RF
2016	0.13 (26)	17	-	-
2017	0.32 (263)	32	-	-
2018	0.33 (155)	35	0.26 (155)	2
2019	0.26 (209)	26	0.27 (209)	2
2020	0.44 (110)	44	0.36 (110)	3
2021	0.32 (127)	32	0.44 (127)	3
2022	0.30 (176)	30	0.46 (176)	3
2023	0.44 (131)	44	0.60 (131)	4
2024	0.27 (119)	24	0.66 (119)	4
Ref. IPO323	0.01	-	0.15	-

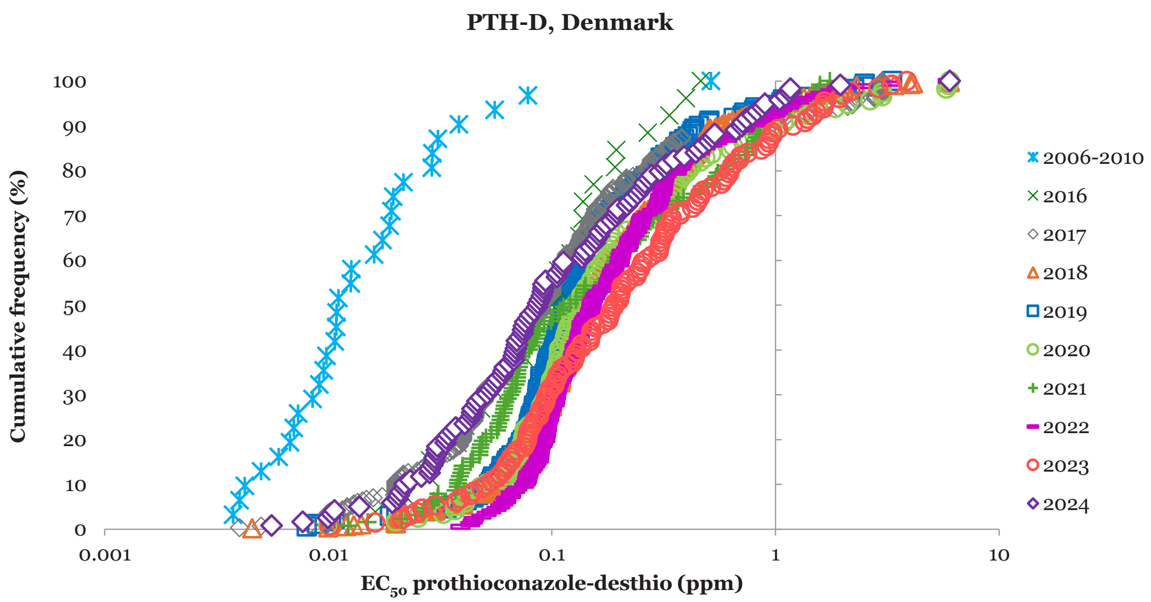

Figure 1. Cumulative frequencies of EC_{50} values (ppm) of prothioconazole-desthio for Danish *Z. tritici* populations from 2016 to 2024. Isolates from 2006 to 2010 are shown for comparison. Each data point represents one isolate.

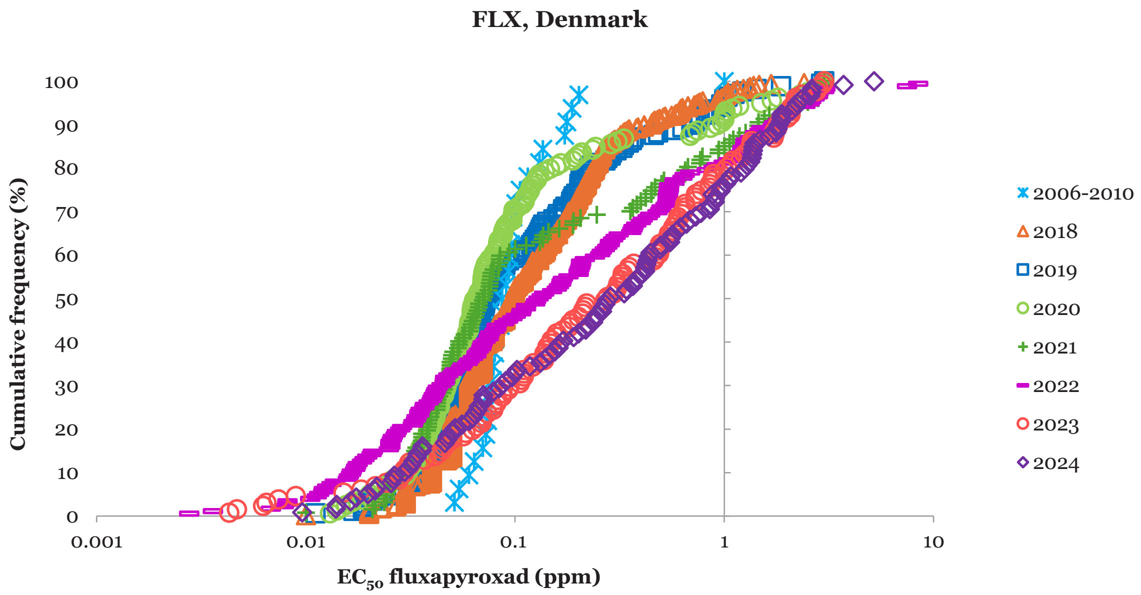

Figure 2. Cumulative frequencies of EC_{50} values (ppm) of fluxapyroxad for Danish *Z. tritici* populations from 2016 to 2024. Isolates from 2006 to 2010 are shown for comparison. Each data point represents one isolate.

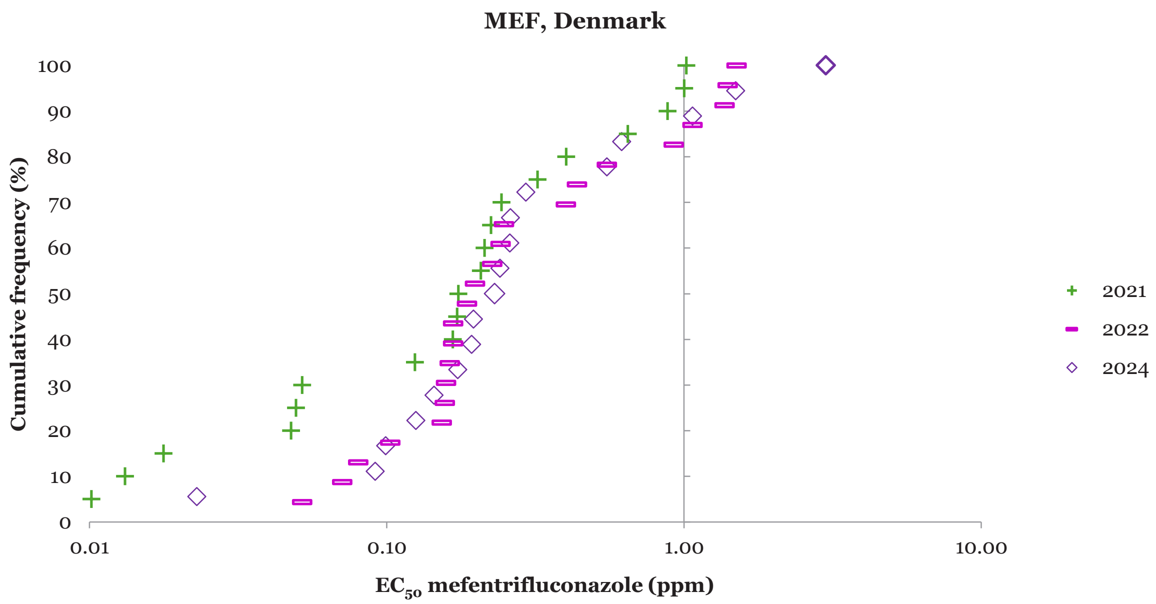

Figure 3. Cumulative frequencies of EC_{50} values (ppm) of mefentrifluconazole for Danish *Z. tritici* populations from 2021, 2022 and 2024. Each data point represents one isolate.

Results – Sweden

The severity of Septoria tritici blotch in Sweden was also moderate to severe in 2024. Samples were collected from 33 sites, but spores could only be isolated from 32 of them.

The average EC_{50} value was 0.21 ppm for prothioconazole-desthio in Sweden in 2024, which is in line with or slightly lower than in 2023 but comparable to previous years' findings (Figure 4). In 2020-23, it was in the range of 0.11-0.30 ppm. Therefore, this year's results showed a slight increase in sensitivity compared with 2023 (0.30 ppm) (Table 4). However, it has previously been discussed that seasons with higher disease pressure and ineffective fungicide timings lead to an increased sensitivity in the population. When comparing the current sensitivity with isolates from 2006 to 2010, it is still clear that a shift has taken place. The sensitivity of the Swedish *Z. tritici* populations was very similar to the Danish populations, and the resistance factor very similar: 23 in Sweden and 24 in Denmark in 2024. Resistance factors from individual sites varied from 2 to 217 in Sweden in 2024 (Table 3), where especially one site in Simrishamn stood out with a high resistance factor.

For fluxapyroxad, the average EC_{50} value in Sweden for 2024 was 0.56 ppm, which was slightly higher compared with the findings of previous years, where the range was between 0.09 ppm and 0.48 ppm (Figure 5; Table 4). Despite this increase, the resistance factor remains low compared with the resistance factor for prothioconazole. The Swedish and the Danish *Z. tritici* populations tested in 2024 had a very similar sensitivity to fluxapyroxad; on average, the resistance factors in Sweden were 1-4 compared with 3-4 in Denmark in 2021-2024.

A subset consisting of one isolate per location was analysed for its sensitivity to mefentrifluconazole. For the majority, the sensitivity was in line with previous years, whereas a few isolates with higher EC_{50} values were also found (Figure 6).

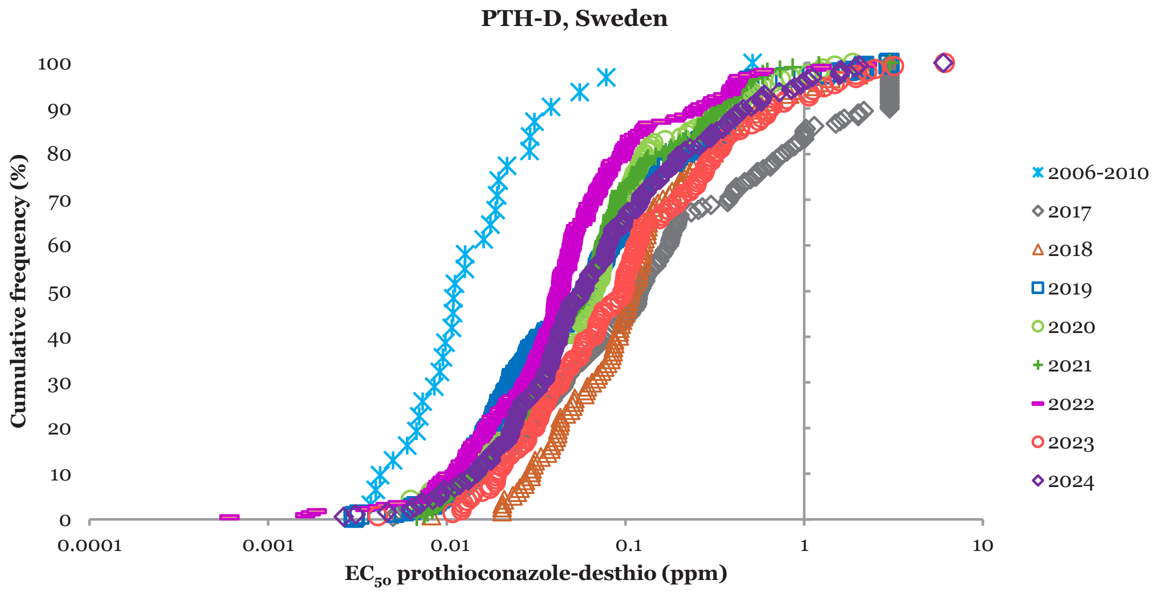

Figure 4. Cumulative frequencies of EC_{50} values (ppm) of prothioconazole-desthio for Swedish *Z. tritici* populations from 2017 to 2024. Isolates from 2006 to 2010 are shown for comparison. Each data point represents one isolate.

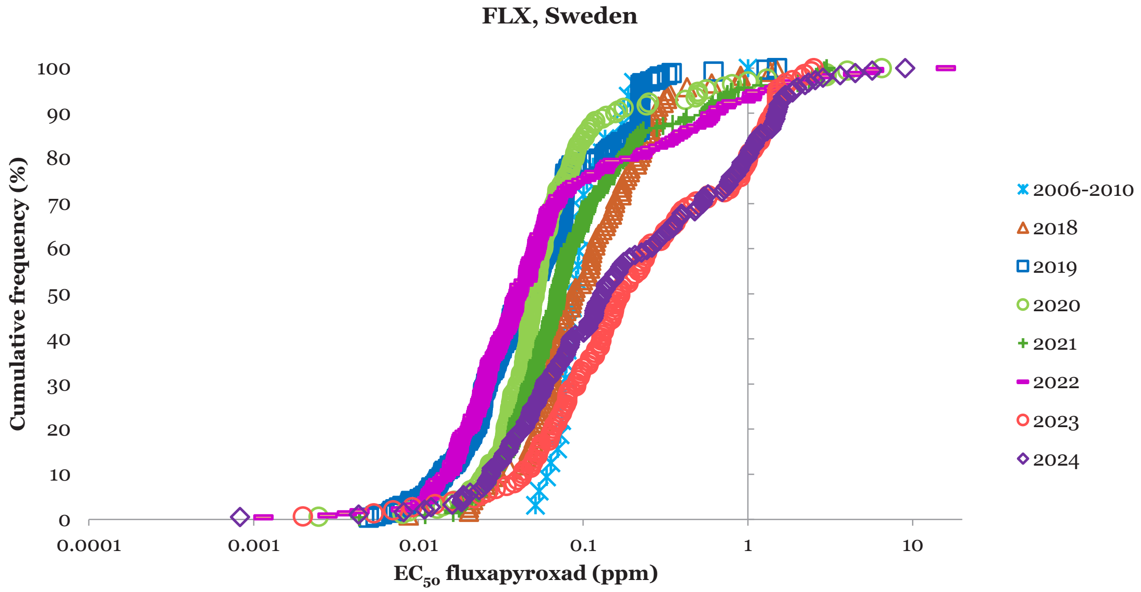

Figure 5. Cumulative frequencies of EC_{50} values (ppm) of fluxapyroxad for Swedish *Z. tritici* populations from 2018 to 2024. Isolates from 2006 to 2010 are shown for comparison. Each data point represents one isolate.

Table 3. Mean EC_{50} values and resistance factors (RF) for prothioconazole-desthio (PTH-D) and fluxapyroxad (FLX) for 187 *Z. tritici* isolates from 33 samples collected in Sweden in 2024.

Location		EC_{50} (ppm)						Number of isolates
		PTH-D	RF	Range	FLX	RF	Range	
24-ZT-SW-01	Stenstorp	0.03	3	0.01-0.06	0.07	0	0.01-0.39	10
24-ZT-SW-02	Götene	0.03	3	0.00-0.10	0.27	2	0.01-1.14	10
24-ZT-SW-03	Skara	0.10	10	0.01-0.37	0.38	3	0.02-1.40	7
24-ZT-SW-04	Lidköping	0.15	15	0.00-0.42	0.10	1	00.0-0.54	10
24-ZT-SW-05	Lidköping	0.08	8	0.02-0.28	0.84	6	0.04-4.48	9
24-ZT-SW-06	Vara	0.14	14	0.02-0.72	0.11	1	0.03-0.27	10
24-ZT-SW-07	Grästorp	0.26	26	0.01-2.02	0.45	3	0.02-1.59	10
24-ZT-SW-08	Nossebro	0.16	16	0.03-0.39	0.54	4	0.08-1.68	4
24-ZT-SW-09	Sollebrunn	0.25	25	0.05-0.84	0.88	6	0.18-1.63	7
24-ZT-SW-10	Mariestad	0.04	4	0.02-0.10	0.07	0	0.02-0.10	5
24-ZT-SW-11	Skövde	0.21	21	0.04-0.38	0.19	1	0.04-0.35	2
24-ZT-SW-12	Söder Möckelby	0.63	63	0.01-1.93	0.29	2	0.04-0.91	4
24-ZT-SW-13	Kastlösa	0.50	50	0.08-1.58	1.86	12	0.08-9.00	8
24-ZT-SW-15	Kalmar	0.06	6	0.01-0.12	0.21	1	0.01-0.76	10
24-ZT-SW-16	Aspnäs, Östervåla	0.08	8	0.01-0.27	0.11	1	0.03-0.33	10
24-ZT-SW-17	Österskog, Borensberg	0.07	7	0.03-0.12	2.85	19	0.02-5.68	2
24-ZT-SW-18	Berga, Linköping	0.16	16	0.02-0.58	0.41	3	0.03-1.86	5
24-ZT-SW-19	Tåå, Nyköping	0.22	22	0.02-0.44	0.78	5	0.07-1.98	3
24-ZT-SW-20	Tåå, Nyköping	0.13	13	0.01-0.30	0.89	6	0.09-1.47	3
24-ZT-SW-21	Örberga, Vadstena	0.03	3	0.02-0.04	0.18	1	0.05-0.31	2
24-ZT-SW-23	Åstorp	0.39	39	0.02-1.58	1.09	7	0.13-1.53	7
24-ZT-SW-24	Trelleborg	0.05	5	0.01-0.12	0.67	4	0.03-2.55	4
24-ZT-SW-26	Sjöbo	0.07	7	0.02-0.22	0.38	3	0.02-1.30	6
24-ZT-SW-27	Bromölla	0.12	12	0.02-0.53	0.82	5	0.03-2.33	9
24-ZT-SW-28	Löderup	0.09	9	0.02-0.26	0.89	6	0.19-2.22	4
24-ZT-SW-29	Glemmingsbro	0.33	33	0.03-0.95	0.64	4	0.03-2.85	10
24-ZT-SW-30	Sölvesborg	0.15	15	0.02-0.6	0.65	4	0.08-1.48	5
24-ZT-SW-31	Simrishamn	2.17	217	0.06-6.0	1.13	8	0.07-3.62	4
24-ZT-SW-32	Halmstad	0.02	2	0.01-0.03	0.26	2	0.04-0.47	2
24-ZT-SW-33	Simrishamn	0.31	31	0.05-1.11	0.79	5	0.00-1.47	5

Table 4. Summary of mean EC_{50} (ppm) values and resistance factors (RF) for prothioconazole-desthio and fluxapyroxad assessed for *Z. tritici* in Sweden. The total numbers of isolates tested are given in brackets.

Year	EC_{50} (ppm)			
	Prothio.-desthio	RF	Fluxapyroxad	RF
2017	0.58 (150)	71	-	-
2018	0.35 (127)	35	0.19 (127)	2
2019	0.17 (341)	17	0.09 (341)	1
2020	0.15 (157)	15	0.14 (157)	1
2021	0.14 (210)	14	0.22 (210)	2
2022	0.11 (224)	11	0.20 (224)	1
2023	0.30 (149)	30	0.48 (149)	3
2024	0.21 (187)	23	0.56 (187)	4
Ref. IPO323	0.01	-	0.15	-

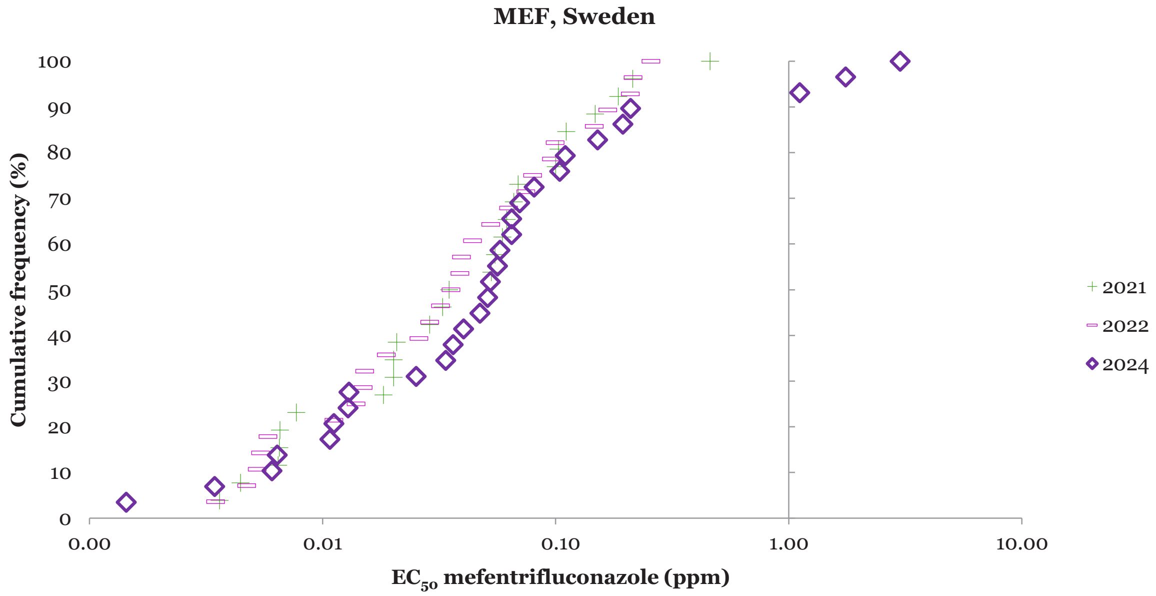

Figure 6. Cumulative frequencies of EC_{50} values (ppm) of mefentrifluconazole for Swedish *Z. tritici* populations from 2021, 2022 and 2024. Each data point represents one isolate.

Mutations detection

From Denmark and Sweden, 48 and 87 isolates were picked randomly from the complete sample pool and tested for four specific mutations, including one CYP51 mutation and three SdhC mutations, conferring resistance to azoles and SDHIs, respectively. From each location, two to three isolates were tested using specific primers. Results are shown in Table 5. The highest frequencies of the CYP51 mutation S524T were found in Denmark (60%), while lower frequencies were found in Sweden (30%), which corresponds to the slightly lower EC_{50} values in Sweden than in Denmark for the azole prothioconazole. The frequency of this mutation has increased recently and is known to cause the highest level of resistance against azoles (Hellin et al., 2020).

The three SdhC mutations showed similar frequencies in Denmark and Sweden for the mutations T79N and H152R, while the frequency of N86S was considerable higher in Denmark with 40% than in Sweden with 27%. The SDH mutations reduce the efficacy of SDHIs including boscalid, fluxapyroxad, bixafen, fluopyram and solatanol. The relatively new mutation S152R was found at similar frequencies in Denmark in 2023 and 2024, while the mutation was not found in Sweden in 2023; in 2024 S152R was found in 7% of isolates in Sweden. As seen previously, N86S was the most widespread SDH mutation in both countries, and the frequency of this mutation increased in Denmark from 32% in 2023 to 40% in 2024, while it was more constant in Sweden with 26% to 27%.

Table 5. CYP51 and SdhC mutations in specific isolates of *Zymoseptoria tritici* collected during 2023 and 2024 and analysed using qPCR as described by Hellin et al. (2020).

		Sweden		Denmark	
		2023	2024	2023	2024
Number of isolates		57	82-87	62	47-48
CYP51	S524T	20 (35%)	26 (30%)	36 (58%)	28 (60%)
SdhC	T79N	2 (4%)	7 (9%)	9 (15%)	4 (8%)
SdhC	N86S	15 (26%)	23 (27%)	20 (32%)	19 (40%)
SdhC	H152R	0 (0%)	6 (7%)	3 (5%)	3 (6%)

From ten EuroWheat trials, leaf samples were collected around GS 75, and *Z. tritici* isolates were analysed for CYP51 and SdhC/SdhB mutations conferring resistance against azoles and SDHIs. The trials were located in Denmark, the UK, Ireland, France, Germany, Poland and Belgium. These analyses were carried out by BASF, using pyrosequencing and qPCR (efficacy data shown in Chapter II).

The frequencies varied widely across Europe (Table 6), which has also been shown previously (Jørgensen et al., 2022). The SdhC mutations are much more common, and N86S was the most widespread among those, followed by T79N. The SdhC mutation H152R causes the highest level of resistance against SDHIs (Hellin et al., 2020), but it is not widespread and was only found in the UK at a low frequency of 10%. However, in the national monitoring this mutation was also found in Denmark at low levels (Table 5).

Several of the CYP51 mutations, which cause resistance against azoles, were found at high frequencies at most locations (Table 7). As mentioned previously, S524T has only recently become widespread and is now present at all tested locations with a minimum frequency of 31-33% in Denmark and France. The highest frequencies were seen in the UK, Ireland and Northern Germany (88-99%), but also in Poland and Belgium these frequencies were high with 79% and 65%, respectively.

Sensitivity analyses were also carried on fluxapyroxad, prothioconazole-desthio and mefentrifluconazole on ten isolates per location, following the method outlined previously. As for the mutation frequencies, the EC_{50} values varied widely across the locations (Table 8). The highest EC_{50} values were seen in the UK, Ireland and Northern Germany, whereas the lowest EC_{50} values were seen in France, Belgium and Denmark. For prothioconazole-desthio, a similar pattern was seen, but the pattern was less clear. Also for mefentrifluconazole, the EC_{50} values were highest in one UK trial followed by one North German trial, and the lowest EC_{50} values were seen in Poland and France.

Table 6. Frequencies of the SdhB mutations H267R, I269V, N225I and T268I and the SdhC mutations N86S, T79N, N86A W80L/S/T, N86T and H152R collected from untreated plots from EuroWheat trials in 2024. Colours signify the following ranges of mutation frequencies: green: 0%, yellow: 1-20%, orange: 21-40%, red: 41-60% and dark red: 61-100%.

Trial ID	Location	SdhB				SdhC					
		H267R	I269V	N225I	T268I	N86S	T79N	N86A	W80L/S/T	N86T	H152R
24328-1	DK	0	0	0	13	23	0	0	13	0	0
24328-2	UK, NIAB	0	0	0	0	50	30	0	0	0	10
24328-3	UK, ADAS	0	0	0	0	56	22	0	0	0	0
24328-4	IE	17	0	0	0	39	50	58	0	0	0
24328-5	FR	0	0	15	0	22	13	0	0	0	0
24328-6	DE, LfL	13	0	0	0	34	13	0	0	0	0
24328-7	DE, JKI	18	0	0	0	50	26	0	0	0	0
24328-8	PL	13	11	0	0	33	22	0	0	0	0
24328-9	BE	0	0	0	0	45	11	57	0	0	0
24328-10	DE, LKSH	14	10	0	0	41	25	0	0	11	0

Table 7. Frequencies of CYP51 mutations collected from untreated plots from EuroWheat trials in 2024. Colours signify the following ranges of mutation frequencies: green: 0%, yellow: 1-20%, orange: 21-40%, red: 41-60%, dark red: 61-100%.

Trial ID	Location	CYP51							CYTn
		D134G	V136A	V136C	S188N	A379G	I381V	S524T	G143A
24328-1	DK	15	27	10	84	41	100	33	99
24328-2	UK, NIAB	43	47	51	73	95	100	99	96
24328-3	UK, ADAS	46	63	35	62	92	100	99	98
24328-4	IE	53	65	35	63	93	100	99	97
24328-5	FR	35	38	33	62	18	100	31	96
24328-6	DE, LfL	65	69	27	43	31	99	50	89
24328-7	DE, JKI	58	63	24	52	47	100	95	83
24328-8	PL	39	40	26	65	44	100	79	93
24328-9	BE	24	41	23	78	43	100	65	96
24328-10	DE, LKSH	44	52	27	65	67	100	88	90

Table 8. Sensitivity (EC_{50}) of *Z. tritici* isolates to the SDHI fungicide fluxapyroxad and the azoles prothioconazole-desthio and mefentrifluconazole across Europe.

EC_{50} (ppm)		Fluxapyroxad		Prothioconazole-desthio		Mefentrifluconazole	
Trial	Country	Avg.	Min.-max.	Avg.	Min.-max.	Avg.	Min.-max.
24328-1	DK	0.59	0.06-1.64	0.27	0.03-0.83	0.60	0.13-1.83
24328-2	UK	1.60	0.42-4.86	0.31	0.07-1.26	0.67	0.12-3.00
24328-3	UK	4.70	0.39-9.00	1.12	0.19-2.81	1.21	0.09-3.00
24328-4	IR	2.89	0.06-9.00	1.70	0.01-6.00	0.75	0.03-3.00
24328-5	FR	0.43	0.03-1.99	0.13	0.04-0.46	0.18	0.04-0.32
24328-6	DE, S	1.17	0.02-5.50	1.26	0.09-5.90	0.49	0.05-3.00
24328-7	DE, N	1.92	0.06-8.96	0.21	0.04-0.38	1.32	0.14-3.00
24328-8	PL	0.70	0.05-1.39	0.38	0.04-0.99	0.20	0.05-0.42
24328-9	BE	0.50	0.03-1.62	0.09	0.03-0.20	0.74	0.01-2.79
24328-10	DE, N	2.35	0.07-9.00	0.47	0.04-1.66	0.73	0.07-2.86

Fungicide resistance in *Pyrenophora teres* in Denmark and Sweden

Each year, the level of fungicide resistance is monitored in *P. teres* populations from both Denmark and Sweden. This monitoring follows the methodology detailed earlier for monitoring resistance in *Z. tritici*.

The sensitivity towards prothioconazole-desthio (PTH-D) and fluxapyroxad (FLX) was analysed for 128 isolates from 13 Danish locations and 137 isolates from 14 Swedish locations in 2024 (Tables 9 and 11). Generally, the net blotch disease severity was moderate.

For each *P. teres* isolate, spores were released into ultrapure water, and the resulting suspensions were homogenised and standardised to a concentration of 4×10^3 spore/ml. Fungicide sensitivity was evaluated using microtitre plates, with technical duplicates for each isolate. Reference isolates REF1803 and REF1804 were included as controls. Stock solutions of prothioconazole-desthio and fluxapyroxad were prepared by dissolving the active ingredients in 80% ethanol. These stock solutions were then combined with a 2x yeast bacto peptone glycerol solution (YBG). The YBG fungicide solutions were added to the microplates, with final concentrations of 5.0, 1.0, 0.2, 0.04, 0.008, 0.0016, 0.00032 and 0 mg/l for prothioconazole-desthio, and 10.0, 2.0, 0.4, 0.08, 0.016, 0.0032, 0.00064 and 0 mg/l for fluxapyroxad. Equal volumes (50 µl) of spore suspension and YBG fungicide solution were added to 96-deep well microplates. The plates were then covered in aluminium foil and incubated at 22°C for five days in darkness. After incubation, the plates were analysed using an ELISA reader at 405 nm. Fungicide sensitivity was quantified by calculating the EC_{50} value, representing the fungicide concentration that reduced fungal growth by 50%. This value was determined through non-linear regression analysis using GraphPad Prism software (Version 9.5.0 (730), November 9, 2022).

The current data contribute to the continuing monitoring of prothioconazole resistance in Denmark (2016-2019, 2022-2024) and Sweden (2016, 2018, 2022-2024) as well as fluxapyroxad resistance in Denmark (2018, 2019, 2022-2024) and Sweden (2018, 2022-2024).

Results – Denmark

In 2024, the average EC_{50} for prothioconazole-desthio in Danish *P. teres* isolates was 0.33 ppm, indicating a decreased sensitivity compared with observations from 2023 (avg. 0.15 ppm) and 2022 (avg. 0.1 ppm) (Figure 7; Table 10). These findings suggest a minor fluctuation in the sensitivity of Danish *P. teres* populations since 2018, while confirming continued susceptibility to prothioconazole-desthio.

Conversely, a marked reduction in fluxapyroxad sensitivity was evident in Danish *P. teres* in 2022. The average EC_{50} reached 1.13 ppm, a substantial increase from the 0.04 ppm and 0.19 ppm recorded in 2018 and 2019, respectively (Table 10). Additionally, the distribution of EC_{50} values in 2022 suggests the emergence of two distinct groups within the Danish *P. teres* population, each exhibiting differing sensitivity patterns (Figure 8). In 2024, this shifting has continued for part of the population, decreasing the proportional size of the more sensitive part of the population.

To summarise, the susceptibility of *P. teres* to prothioconazole-desthio in Denmark showed only a small change in 2024, whereas a notable decline in fluxapyroxad sensitivity has been observed since 2022 and has continued in 2024.

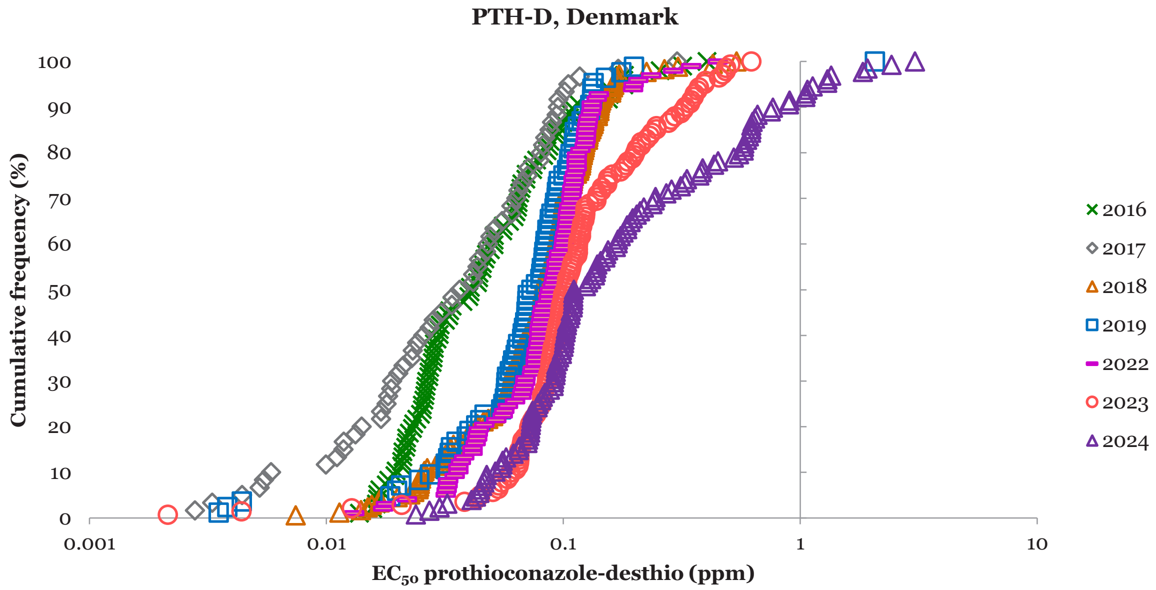

Figure 7. Cumulative frequencies of EC_{50} values (ppm) of prothioconazole-desthio for Danish *P. teres* populations from 2016 to 2024. Each data point represents one isolate.

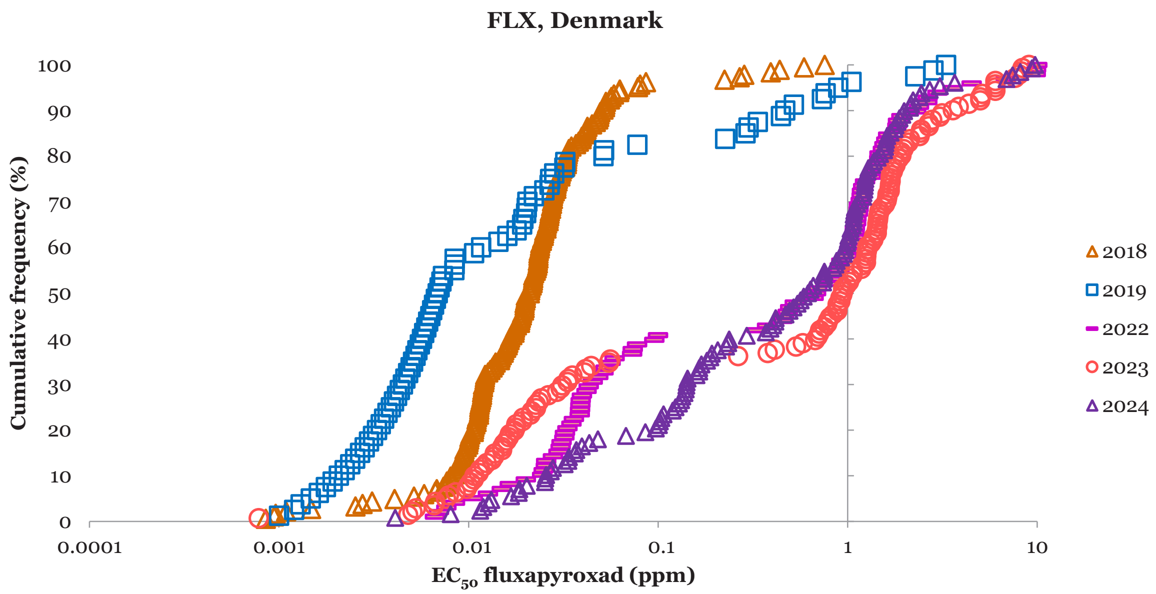

Figure 8. Cumulative frequencies of EC_{50} values (ppm) of fluxapyroxad for Danish *P. teres* populations from 2018 to 2024. Each data point represents one isolate.

Table 9. Mean EC_{50} (ppm) values and resistance factors (RF) for prothioconazole-desthio (PTH-D) and fluxapyroxad (FLX) for 128 *P. teres* isolates from 13 Danish locations in 2024.

Location		EC_{50} (ppm)						Number of isolates
		PTH-D	RF	Range	FLX	RF	Range	
24-PT-DK-01	Brønderslev	0.06	1	0.02-0.24	1.10	16	0.03-9.36	10
24-PT-DK-02	Ringsted	0.11	1	0.05-0.17	1.01	14	0.03-2.21	10
24-PT-DK-03	Rønde	0.10	1	0.06-0.19	1.73	25	0.37-8.12	10
24-PT-DK-04	Aarhus	0.13	2	0.07-0.24	0.97	14	0.04-1.59	10
24-PT-DK-05	Åkirkeby	0.36	5	0.05-0.77	1.65	23	0.00-9.75	10
24-PT-DK-06	Åkirkeby	0.60	8	0.19-1.07	2.75	39	0.29-7.42	10
24-PT-DK-07	Åkirkeby	0.90	13	0.24-2.43	0.14	2	0.09-0.23	9
24-PT-DK-08	Åkirkeby	0.59	8	0.18-1.06	0.20	3	0.10-0.49	9
24-PT-DK-09	Rønde	1.07	15	0.11-3.05	0.16	2	0.07-0.24	10
24-PT-DK-10	Vojens	0.07	1	0.04-0.09	1.68	24	0.84-2.71	10
24-PT-DK-11	Kolding	0.10	1	0.04-0.17	0.77	11	0.02-1.44	10
24-PT-DK-13	Ringsted	0.11	2	0.06-0.15	0.61	9	0.01-1.69	10
24-PT-DK-14	Flakkebjerg	0.11	2	0.04-0.21	0.77	11	0.01-1.94	10

Table 10. Summary of mean EC_{50} (ppm) values for prothioconazole-desthio and fluxapyroxad assessed for *P. teres* in Denmark. The total numbers of isolates tested are given in brackets.

Year	Prothio.-desthio	Fluxapyroxad
2016	0.06 (97)	-
2017	0.05 (60)	-
2018	0.09 (175)	0.04 (184)
2019	0.10 (84)	0.19 (80)
2022	0.10 (97)	1.13 (97)
2023	0.15 (141)	1.42 (142)
2024	0.33 (128)	1.05 (128)
Average	0.126	0.766

Results – Sweden

In 2024, the average EC_{50} for prothioconazole-desthio in Swedish *P. teres* isolates was 0.10 ppm, indicating a similar sensitivity compared with observations from 2023 (Figure 9; Table 12). These findings suggest an unclear fluctuation in the sensitivity of Swedish *P. teres* populations since 2022, while confirming continued susceptibility to prothioconazole-desthio.

Conversely, a marked reduction in fluxapyroxad sensitivity was evident in Swedish *P. teres* in 2024. The average EC_{50} reached 1.56 ppm, a substantial increase from the 0.6 ppm recorded in 2023 and even more so compared with 0.03 ppm in 2018 (Table 12). Additionally, the distribution of EC_{50} values in 2024 suggests the emergence of two distinct groups within the Swedish *P. teres* population, each exhibiting differing sensitivity patterns (Figure 10). In 2024, this shifting has continued for part of the population, decreasing the proportional size of the more sensitive part of the population.

To summarise, the susceptibility of *P. teres* to prothioconazole-desthio in Sweden showed only a small change in 2024, whereas a notable decline in fluxapyroxad sensitivity has been observed since 2022 and has continued in 2024. Ongoing investigation tries to clarify which mutations cause the major shift seen in both Denmark and Sweden.

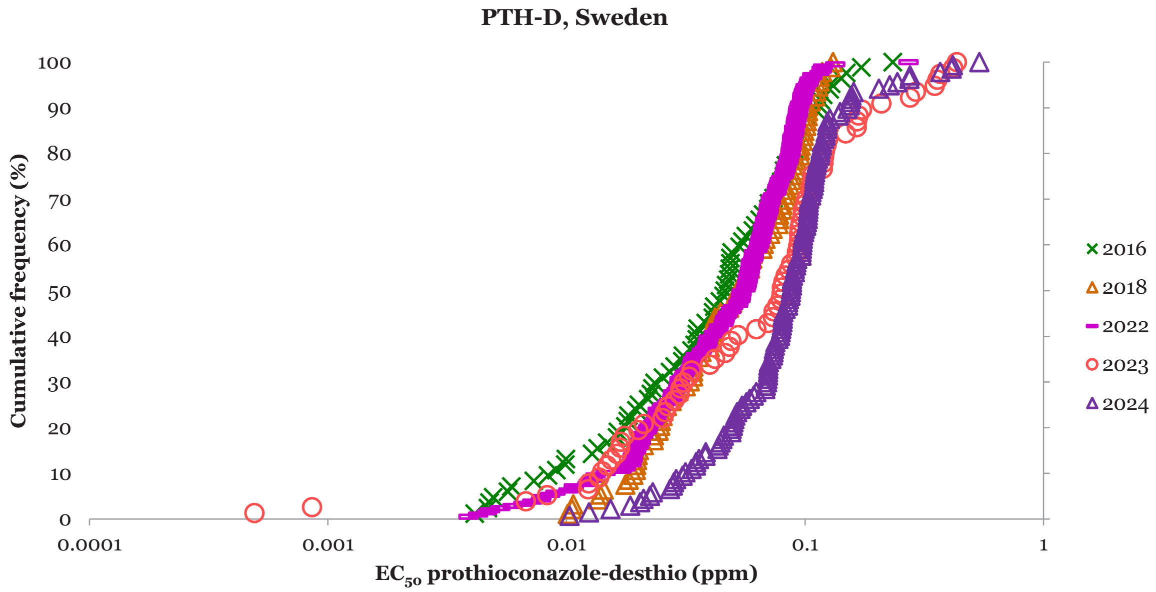

Figure 9. Cumulative frequencies of EC_{50} values (ppm) of prothioconazole-desthio for Swedish *P. teres* populations from 2016 to 2024. Each data point represents one isolate.

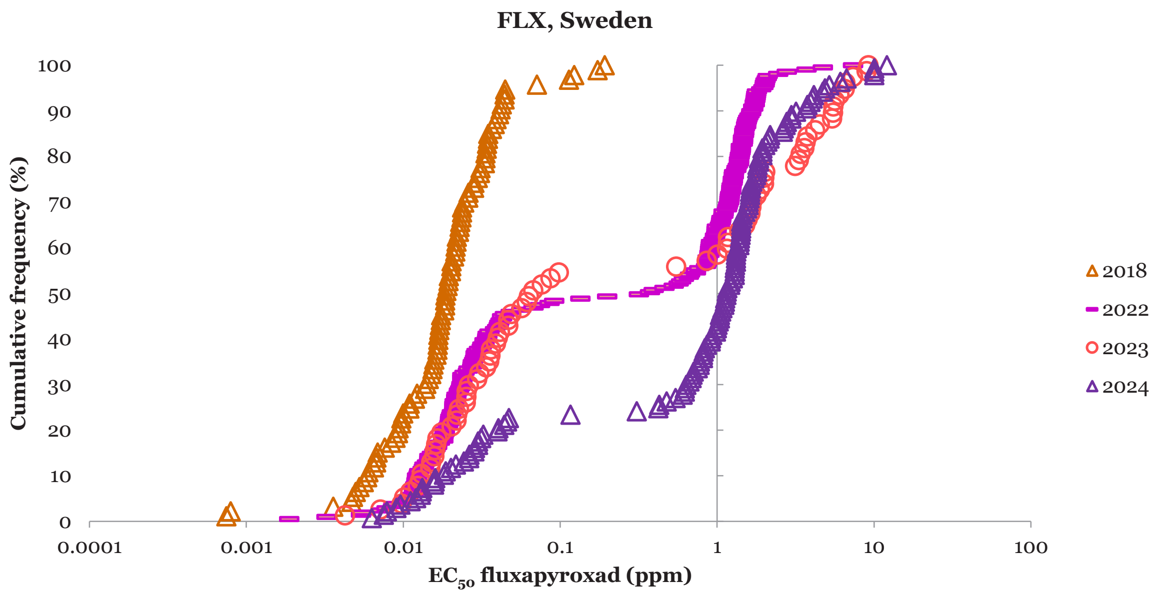

Figure 10. Cumulative frequencies of EC_{50} values (ppm) of fluxapyroxad for Swedish *P. teres* populations from 2018 to 2024. Each data point represents one isolate.

Table 11. Mean EC_{50} (ppm) values and resistance factors (RF) for prothioconazole-desthio (PTH-D) and fluxapyroxad (FLX) for 137 *P. teres* isolates from 14 Swedish locations in 2024.

Location		EC_{50} (ppm)						Number of isolates
		PTH-D	RF	Range	FLX	RF	Range	
24-PT-SW-01	Söderköping	0.04	1	0.02-0.07	4.01	57	0.48-12.06	9
24-PT-SW-02	Grästorp	0.10	1	0.03-0.16	1.05	15	0.01-1.67	10
24-PT-SW-03	Lindköping	0.05	1	0.01-0.15	0.15	2	0.01-0.62	8
24-PT-SW-04	Falköping	0.05	1	0.02-0.08	0.88	12	0.02-1.42	10
24-PT-SW-05	Töreboda	0.09	1	0.05-0.16	0.21	3	0.01-1.06	10
24-PT-SW-06	Piteå	0.07	1	0.01-0.27	0.03	0	0.02-0.05	10
24-PT-SW-07	Åsköping	0.08	1	0.05-0.12	1.29	18	0.81-1.64	10
24-PT-SW-08	Hallsberg	0.07	1	0.03-0.12	0.80	11	0.01-1.55	10
24-PT-SW-09	Hallsberg	0.15	2	0.09-0.37	1.95	28	0.60-4.13	10
24-PT-SW-10	Klockirke	0.11	2	0.07-0.16	3.55	50	0.04-10.0	10
24-PT-SW-11	Trälleborg	0.15	2	0.07-0.54	0.98	14	0.01-2.03	10
24-PT-SW-12	Åstorp	0.16	2	0.06-0.42	3.81	54	1.15-10.0	10
24-PT-SW-13	Simrishamn	0.09	1	0.06-0.11	1.41	20	0.69-2.09	10
24-PT-SW-14	Lund	0.13	2	0.07-0.41	1.70	24	1.30-2.78	10

Table 12. Summary of mean EC_{50} (ppm) values for prothioconazole-desthio (PTH-D) and fluxapyroxad (FLX) assessed for *P. teres* in Sweden. The total numbers of isolates tested are given in brackets.

Year	Prothio.-desthio	Fluxapyroxad
2016	0.06 (84)	-
2018	0.06 (93)	0.03 (93)
2022	0.05 (209)	0.71 (209)
2023	0.10 (77)	0.60 (77)
2024	0.10 (137)	1.56 (137)
Average	0.074	0.725

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VI Impact of cultivar mixtures on Fusarium head blight in winter wheat

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In both 2023 and 2024, AU Flakkebjerg conducted field experiments in winter wheat to investigate the disease-reducing effects of cultivar mixtures on Fusarium head blight. The trials were laid out as split-plot trials with cultivars as the first factor and control measures as the second factor. Three cultivars were included in the experiment: Rembrandt, Informer and Sheriff, chosen as representatives of susceptible, medium susceptible and moderately resistant cultivars, respectively. In addition, a mixture of the three cultivars was included with the aim to investigate if mixtures can reduce the risk of disease development. The experiment also included the testing of different control strategies, which included both a chemical solution and two solutions which involved the use of biological control agents (BCAs). Spraying was done twice in the experiment at growth stages (GS) 37-39 and GS 61-65. Spraying applied at GS 37-39 included the use of Balaya (100 g mefentrifluconazole + 100 g pyraclostrobin/l) (BASF A/S) and 3.0 l Thiopron (825 g sulphur/l), while treatments applied at GS 61-65 included a mixture of Propulse SE 250 (125 g prothioconazole + 125 g fluopyram/l) + 0.25 Folicur Xpert (80 g prothioconazole + 160 g tebuconazole/l) (Bayer Crop Science) or the use of Lalstop G46 WG (*Clonostachys rosea* strain J1446). All plots were harvested, and yields were adjusted to 15% moisture and grain quality measured, using NIT (reference). Mycotoxin was measured from ground grain samples, using HPLC-MS, only analysing one sample per treatment, using a mutual sample consisting of input from the three replicates.

Grains infected with *Fusarium culmorum* and *Fusarium graminearum* were laid out in May at GS 39. In the dry season 2023, the experiment was irrigated three times (23 May: 14 mm, 30 May: 21 mm and 15 June: 15 mm) to promote *Fusarium* infection and development. In 2024, the season was sufficiently covered by rain events to ensure a good development. Diseases were scored regularly for both leaf diseases and Fusarium head blight. Regarding leaf diseases, the EPPO guidelines were used. Visual scoring for the disease severity at specific leaf layers was carried out based on an average score of the plot. Assessment for Fusarium head blight was done by counting the number of diseased heads per 4-metre row per plot, or – at lower incidences – by counting the number of diseased heads per plot.

Results

The attack of Fusarium head blight in 2024 was very severe, following several rain events. The level of Septoria tritici blotch (*Zymoseptoria tritici*) was overall low to moderate, with also a minor to moderate attack of brown rust (*Puccinia triticina*) being present. Clear differences in severity were seen between the included cultivars. Rembrandt was most susceptible to both Septoria tritici blotch and brown rust and was the most severely infected cultivar, while Sheriff was least infected by both diseases.

The results in 2024 showed that there was a reduction in both Fusarium head blight and the amount of mycotoxin measured as deoxynivalenol (DON) in the cultivar mixture compared with the average of the individual cultivars. Data are shown from untreated plots (Table 1) as well as across all treatments (Table 2). The reduction in the attack of Fusarium head blight in the cultivar mixture varied between 15% and 40% depending on the timing of the assessment. Overall, the reductions in mixtures were most significant in non-fungicide treated plots: 27-40% (Table 1). The reduction in DON was 33% in untreated plots and only 3% across all treatments. The cultivar mixture also contributed to a reduction in Septoria tritici blotch and brown rust, and minor yield benefits were recorded in untreated plots. This was confirmed when measured across all treatments with the exception of brown rust, which was not reduced (Table 2). Yield data were clearly impacted by a severe attack of Fusarium head blight in 2024 when especially Rembrandt was severely affected, resulting in a significantly lower yield and higher DON content, but also in lower thousand grain weight (TGW), % starch and specific weight. This was seen for untreated as well as across all treatments (Tables 1 and 2).

As expected, the treatments applied for control of Fusarium head blight and foliar diseases resulted in a clear reduction in disease levels. The standard chemical reference gave the most pronounced reductions, but a reduction resulting from the biosolutions (Lalstop G46 WG with *Clonostachus rosea*) was also seen (Table 3). Septoria tritici blotch and brown rust were significantly reduced by all treatments. The two biosolutions reduced *Fusarium* significantly at the early timing, while this was not the case at the later assessment. The chemical treatments reduced the content of mycotoxin by 67%, while the biosolutions only resulted in a slightly lower level of DON. Two of the three treatments gave significantly higher yields compared with the untreated plots. Only treatments based on sulphur and Lalstop G46 WG did not give significantly higher yields. The mixed treatment using Balaya followed by a BCA resulted in a significant yield increase and also a positive impact on TGW. The water content in grains was significantly increased for chemical treatments as a result of a postponed ripening of the crop following better disease control.

Detailed data from the 2023 season are shown in the report "Applied Crop Protection 2023" (Beck et al., 2024). Data from the two testing seasons are summarised in Figure 1.

The project was financed by the Danish Environmental Protection Agency's pesticide research programme and by the EU project Adopt-IPM.

Discussion

Across the two seasons, the two trials in winter wheat have shown that attack of Fusarium head blight can be reduced in cultivar mixtures compared with the average of the included cultivars. To our knowledge, no other data have so far shown effects on Fusarium head blight from the use of mixtures.

The reductions in untreated cultivars were 15-40% in 2024 and 30-57% in 2023. The reductions in the content of the mycotoxin DON in untreated plots were 25% and 33% in 2023 and 2024, respectively, but only 3-5% when measured across all treatments. The level of DON was very high in 2024 and far beyond the maximum acceptable threshold of 1250 ppb, following a severe attack. The reduction of leaf diseases from the mixtures was in line with data from other investigations (Vestergaard and Jørgensen, 2024).

Yield data were clearly impacted by the severe attack of Fusarium head blight, particularly in 2024 when the attack especially in Rembrandt was very severe and led to a significantly lower yield, higher DON content but also lower TGW, % starch and specific weight. It is well known that Fusarium head blight has a negative impact on grain quality and typically leads to more shrivelled grains, which again gives lower TGW and specific weight (Salgado et al., 2015).

In conclusion, a positive mixture effect on *Fusarium* infections, leaf diseases, yield and grain quality parameters was seen both from untreated plots (Table 1) and although less pronounced also to a minor extent when assessed across all treatments (Table 2). As expected, the chemical treatment increased the yield significantly as well as the specific weight and the TGW (Table 3).

Data from the two seasons are summarised in Figure 1 for the untreated and the chemical treatment (0.75 l Balaya / 0.5 l Propulse SE 250 + 0.25 l Folicur Xpert) and illustrate the control effect and yield improvements achieved from fungicides on the three different cultivars and the mixture of the three cultivars.

Table 1. Data from untreated plots with three solo cultivars and the mixture of the three cultivars. Trial 24353-1. Different letters indicate significant differences based on P-values ≤ 0.05. DON = deoxynivalenol.

Cultivars	Number of *Fusarium*-infected ears		DON, ppb	% Septoria tritici blotch		% brown rust, GS 79	% GLA, GS 83
Date/Leaf number	**28 June**	**4 July**	**Grain**	**Leaf 3**	**Flag leaf**	**Flag leaf**	**Flag leaf**
Cultivar mixture	10 b	30 b	5521	6.7 b	18.9 b	3.2 bc	50 a
Sheriff	5 b	24 b	6997	11.0 b	13.1 b	1.1 c	63.3 a
Rembrandt	38 a	55 a	12466	20.0 a	38.3 a	10 a	15 b
Informer	7 b	35 b	5172	4.0 b	19.6 b	6.3 b	60 a
Average of solo cultivars	17	38	8212	11.7	23.7	5.8	46.1
% benefit of mixture	40%	27%	33%	42%	20%	44%	8.4%

Cultivars	Specific weight, kg/hl	TGW, g	% starch	% moisture	% gluten	Yield, dt/ha
Cultivar mixture	69.5 a	43.4 a	68.7 a	15.3	19.1 b	82.7 a
Sheriff	68.9 a	38.2 b	68.3 a	15.4	20.6 b	80.6 a
Rembrandt	55.2 b	31.8 c	66.7 b	14.8	22.8 a	58.7 b
Informer	68.7 a	45.3 a	68.3 a	15.2	20.0 b	80.6 a
Average of solo cultivars	64.3	38.4	67.8	15.1	21.1	73.3
% benefit of mixture	8%	13%	1.3%	1.3%	9.5%	13%

Table 2. Data from across all treatments with three solo cultivars and the mixture of the three cultivars. Impact on Fusarium head blight, brown rust, Septoria tritici blotch, yield and grain quality. Trial 24353-1. Different letters indicate significant differences based on P-values ≤ 0.05. DON = deoxynivalenol.

Cultivars	Number of *Fusarium*-infected ears		DON, ppb	% Septoria tritici blotch		% brown rust	% GLA, GS 83
Date/Leaf number	**28 June**	**4 July**	**Grain**	**Leaf 3, GS 55**	**Flag leaf, GS 79**	**Flag leaf, GS 79**	**Flag leaf, GS 83**
Cultivar mixture	7.8 b	27.1 b	6409	5.1 b	6.3 ab	1.4 ab	64.6 a
Sheriff	3.5 b	17.9 b	4667	8.8 b	3.5 b	0.3 c	72.5 a
Rembrandt	26.7 a	55.4 a	10345	17.5 a	13.1 a	2.5 a	34.6 b
Informer	4.2 b	22.5 b	4885	4.0 b	4.3 b	1.2 b	64.6 a
Average of solo cultivars	11.4	31.9	6632	10.1	10.7	1.3	57.2
% benefit of mixture	31	15	3	49	7.4	-8	13

Cultivars	Specific weight, kg/hl	TGW, g	% starch	% moisture	% gluten	Yield, dt/ha
Cultivar mixture	69.0 a	44.4 ab	68.7 a	15.4 a	19.9 b	86.6 a
Sheriff	71.2 a	41.6 b	68.9 a	15.6 a	19.9 b	89.1 a
Rembrandt	59.3 b	35.5 c	67.4 b	14.9 b	21.4 a	67.5 b
Informer	69.1 a	47.4 a	68.4 a	15.4 a	20.0 b	86.9 a
Average of solo cultivars	66.5	41.5	68.2	15.3	20.4	81.2
% benefit of mixture	3.8	7%	0.7%	0.7%	2.5%	6.6

Table 3. Data showing impact on Fusarium head blight, brown rust, Septoria tritici blotch, yield and grain quality from different control treatments from across all cultivars in the trial (24353-1). Different letters indicate significant differences based on P-values ≤ 0.05. DON = deoxynivalenol.

Treatments (l/ha) applied at GS 37-39 and GS 62-65	Number of *Fusarium*-infected ears		DON, ppb	% brown rust	% *Septoria*	GLA
	28 June	4 July	Grain	Flag leaf	Flag leaf	Flag leaf, GS 83
Untreated	15.2 a	37.9 a	7342	4.1 a	22.9 a	47.1 b
0.75 Balaya / 0.5 Propulse SE 250 + 0.25 Folicur Xpert	3.9 c	18.3 b	4884	0.2 c	2.5 c	72.9 a
3.0 Thiopron / 0.3 Lalstop G46 WG	11.6 b	34.2 a	7118	2.3 b	13.9 b	51.3 ab
0.5 Balaya / 0.3 Lalstop G46 WG	11.4 b	32.5 a	6963	0.3 c	2.8 c	65.0 ab

Treatments (l/ha) applied at GS 37-39 and GS 62-65	Specific weight, kg/hl	TGW, g	% starch	% moisture	% gluten	Yield, dt/ha
Untreated	65.6 b	39.3 b	68.0 a	15.2 c	20.6 a	75.7 c
0.75 Balaya / 0.5 Propulse SE 250 + 0.25 Folicur Xpert	69.9.a	45.2 a	68.6 a	15.6 a	20.2 a	89.8 a
3.0 Thiopron / 0.3 Lalstop G46 WG	65.7 ab	40.1 b	68.2 a	15.2 c	20.3 a	79.0 bc
0.5 Balaya / 0.3 Lalstop G46 WG	67.3 ab	43.6 a	68.6 a	15.4 b	20.0 a	85.7 ab

Balaya (100 g mefentrifluconazole + 100 g pyraclostrobin/l) (BASF A/S); Propulse SE 250 (125 g prothioconazole + 125 g fluopyram/l) + Folicur Xpert (80 g prothioconazole + 160 g tebuconazole/l) (Bayer Crop Science), Thiopron (sulphur), Lalstop G46 WG (*Clonostachys rosea* strain J1446).

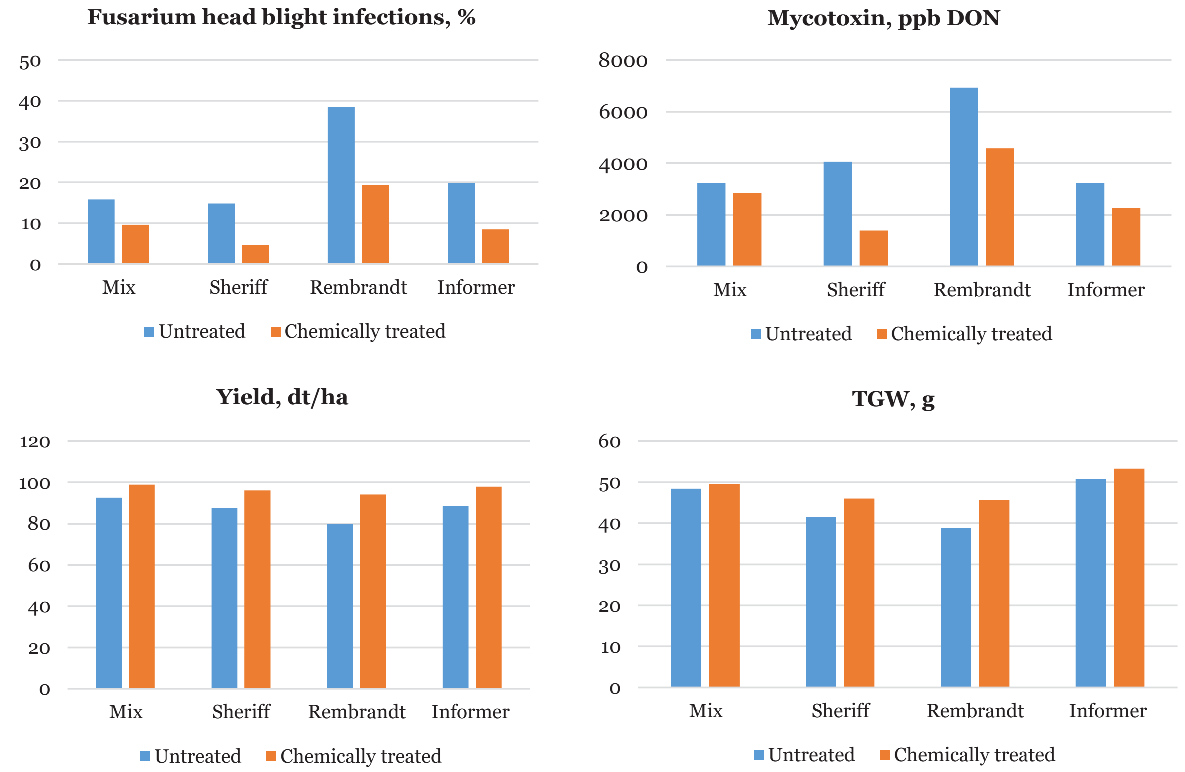

Figure 1. Average attack of Fusarium head blight (%), measurements of DON (ppb) in grain and yield and TGW based on two trials. Data from untreated and the reference chemical treatment, which were consistent across both seasons.

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VII Fungicide anti-resistance strategies in managing potato late blight

Isaac Kwesi Abuley & Jens Grønbech Hansen

Background

Late blight, caused by *Phytophthora infestans*, is a devastating disease that leads to significant yield losses in potato production worldwide. Fungicides remain a cornerstone of late blight management; however, the emergence of fungicide-resistant pathogen isolates poses a serious threat to their continued effectiveness. To preserve the efficacy of available fungicides, anti-resistance strategies are essential.

Ideally, such strategies should be implemented proactively to prevent or delay the emergence of resistant isolates. In practice, however, anti-resistance measures are often adopted reactively after resistant strains have already become established in the pathogen population.

Recently, widespread resistance to the carboxylic acid amide (CAA) fungicide mandipropamid was reported in Denmark. The *P. infestans* population responsible for this resistance was identified as the EU43 genotype (Abuley et al., 2023). First detected in Denmark in 2018, EU43 has since spread to several other European countries. The emergence of mandipropamid resistance is particularly concerning as this fungicide is one of the most important tools for late blight control in Denmark.

Danish potato growers have access to only a limited number of effective active ingredients. As such, discontinuing the use of mandipropamid is not a viable option. Instead, innovative strategies are needed to integrate mandipropamid with other fungicides in a way that maintains effective disease control while minimising the selection pressure for resistant isolates. Additionally, these strategies should aim to prevent the development of resistance to the remaining active ingredients.

The objective of this study was to assess the efficacy of various fungicide anti-resistance strategies – including mixtures and alternation schemes, with and without mandipropamid – in managing late blight under field conditions dominated by the EU43 genotype of *P. infestans*.

Materials and methods

Experimental site and design

The experiment was conducted in 2024 at AU Flakkebjerg, using the starch potato variety Kuras. Ten fungicide treatment strategies were evaluated in a randomised complete block design with four replications. The treatments were as follows:

1. Untreated control: No fungicide application for late blight control.
2. Solo Revus: Revus (mandipropamid) applied at variable dose rates and intervals. This served as a reference for the effect of mandipropamid alone.
3. Solo Shirlan: Shirlan Ultra (fluazinam) applied at variable dose rates and intervals. This served as a reference for the effect of fluazinam alone.
4. Half-dose Mixture-1 (Revus + Shirlan): A mixture of Revus and Shirlan Ultra applied at variable dose rates and intervals. The full rate in this treatment consisted of half the recommended dose of each fungicide: 0.3 l/ha Revus and 0.2 l/ha Shirlan Ultra.

5. Half-dose Mixture-2 (Sporax + Zorvec): A mixture of Sporax (propamocarb) and Zorvec Enicade (oxathiapiprolin) applied at variable dose rates and intervals. The full rate consisted of 0.7 l/ha Sporax (half of the recommended 1.4 l/ha) and 0.075 l/ha Zorvec Enicade (half of the recommended 0.15 l/ha).
6. Mixture_Alternation: Alternating applications of Half-dose Mixture-1 and Half-dose Mixture-2, applied at variable dose rates and intervals.
7. Half-dose Mixture-1_Reference: Revus and Shirlan Ultra applied at fixed half-dose rates (0.3 l/ha and 0.2 l/ha, respectively) whenever spraying was deemed necessary.
8. Half-dose Mixture-2_Reference: Sporax and Zorvec Enicade applied at fixed half-dose rates (0.7 l/ha and 0.075 l/ha, respectively) whenever spraying was necessary.
9. Full-dose Mixture-1: Revus and Shirlan Ultra applied at full recommended rates (0.6 l/ha and 0.4 l/ha, respectively) whenever spraying was necessary.
10. Full-dose Mixture-2: Sporax and Zorvec Enicade applied at full recommended rates (1.4 l/ha and 0.15 l/ha, respectively) whenever spraying was necessary.

Inoculation and disease assessment

A mixture of *P. infestans* isolates, including mandipropamid-resistant EU43 genotypes, was used to inoculate spreader rows surrounding the trial plots. Inoculation was performed on 25 June 2024, using a sporangial suspension containing 10,000 sporangia/ml. Disease assessments were conducted weekly from the onset of late blight symptoms. The final disease assessment was used to evaluate the effectiveness of the different fungicide strategies.

Tuber and starch yield assessment

Tubers were harvested from the two central rows of each plot (15 m^2) in late September. Starch yield was determined using the underwater weight method on a 5,000 g tuber sample. Starch yield was used as a key indicator of treatment performance.

Data analysis

All statistical analyses were conducted using the R programming language (R Core Team, 2025). A Gaussian linear model was fitted to the final disease severity and starch yield data, using the "lm" function (R Core Team, 2025). Treatment effects were assessed using analysis of variance (ANOVA) via the "anova" function. Post-hoc comparisons of treatment means were performed using the "emmeans" function from the emmeans package (Lenth, 2025). All plots were made with the ggplot2 R package (Wickham, 2016).

Results

Fungicide application schedule for each strategy is shown in Table 1. There was a need to apply fungicides every week, except on 22 August when the late blight infection risk was too low to prompt fungicide application.

Table 1. Fungicide application of various anti-resistant strategies evaluated on the potato cultivar Kuras.

Strategy[1]	Fungicide (unit)[2]	03 July	11 July	18 July	24 July	31 July	08 Aug.	15 Aug.	22 Aug.	29 Aug.	05 Sep.	12 Sep.
Solo Revus**	Revus (l/ha)	0.45	0.6	0.6	0.45	0.3	0.45	0.3		0.3	0.3	0.45
Solo Shirlan**	Shirlan Ultra (l/ha)	0.3	0.4	0.4	0.3	0.2	0.3	0.2		0.2	0.2	0.3
Half-dose Mixture-1**	Revus (l/ha)	0.225	0.3	0.3	0.225	0.15	0.225	0.15		0.15	0.15	0.225
	Shirlan Ultra (l/ha)	0.15	0.2	0.2	0.15	0.1	0.15	0.1		0.1	0.1	0.15
Half-dose Mixture-2**	Sporax (l/ha)	0.525	0.7	0.7	0.525	0.35	0.525	0.35			0.35	0.525
	Zorvec Enicade (l/ha)	0.05625	0.075	0.075	0.05625	0.0375	0.05625	0.0375		0.0375	0.0375	0.05625
Mixture_Alternation**	Revus (l/ha)	0.225			0.225	0.15		0.15			0.15	
	Shirlan Ultra (l/ha)	0.15			0.15	0.1		0.1			0.1	
	Sporax (l/ha)		0.7	0.7		0.35	0.526			0.35		0.525
	Zorvec Enicade (l/ha)		0.075	0.075		0.0375	0.05625			0.0375		0.05625
Half-dose Mixture-1_Reference*	Revus (l/ha)	0.3	0.3	0.3	0.3	0.3	0.3	0.3		0.3	0.3	0.3
	Shirlan Ultra (l/ha)	0.2	0.2	0.2	0.2	0.2	0.2	0.2		0.2	0.2	0.2
Half-dose Mixture-2_Reference*	Sporax (l/ha)	0.7	0.7	0.7	0.7	0.7	0.7	0.7		0.7	0.7	0.7
	Zorvec Enicade (l/ha)	0.075	0.075	0.075	0.075	0.075	0.075	0.075		0.075	0.075	0.075
Full-dose Mixture-1*	Revus (l/ha)	0.6	0.6	0.6	0.6	0.6	0.6	0.6		0.6	0.6	0.6
	Shirlan Ultra (l/ha)	0.4	0.4	0.4	0.4	0.4	0.4	0.4		0.4	0.4	0.4
Full-dose Mixture-2*	Sporax (l/ha)	1.4	1.4	1.4	1.4	1.4	1.4	1.4		1.4	1.4	1.4
	Zorvec Enicade (l/ha)	0.15	0.15	0.15	0.15	0.15	0.15	0.15		0.15	0.15	0.15

[1]Strategies marked with one asterisk (*) were sprayed at a fixed dosage of fungicides, while those that are marked with double asterisks (**) were sprayed with variable dosages according to the BlightManager Decision Support System (DSS). All treatments were only sprayed when BlightManager DSS identified a late blight risk period.

[2]The active ingredients in the fungicides are as follows: Revus contains 250 g/l mandipropamid, Shirlan Ultra contains 500 g/l fluazinam, Sporax contains 605 g/l propamocarb and Zorvec Enicade contains 100 g/l oxathiapiprolin.

Figure 1 compares the severity of late blight and the treatment frequency index (TFI) for the various strategies. The solo Revus strategy failed to provide effective late blight control compared with other strategies. Except for solo Revus, there was an absence of significant differences between the strategies for disease severity. However, the most effective anti-resistant strategy was the mixture and alternation strategy. In terms of the TFI, the full dose mixtures resulted in 20 TFI compared with 10-7 TFI for the strategies that used reduced/half dose mixtures applied at fixed or variable dose rates depending on the infection pressure. The result also shows no significant difference between the strategies that applied a fixed dosage or variable dosage based on BlightManager DSS for disease severity. Rather, the variable dosage strategies reduced the fungicide usage (TFI) compared with all the fixed dosage strategies.

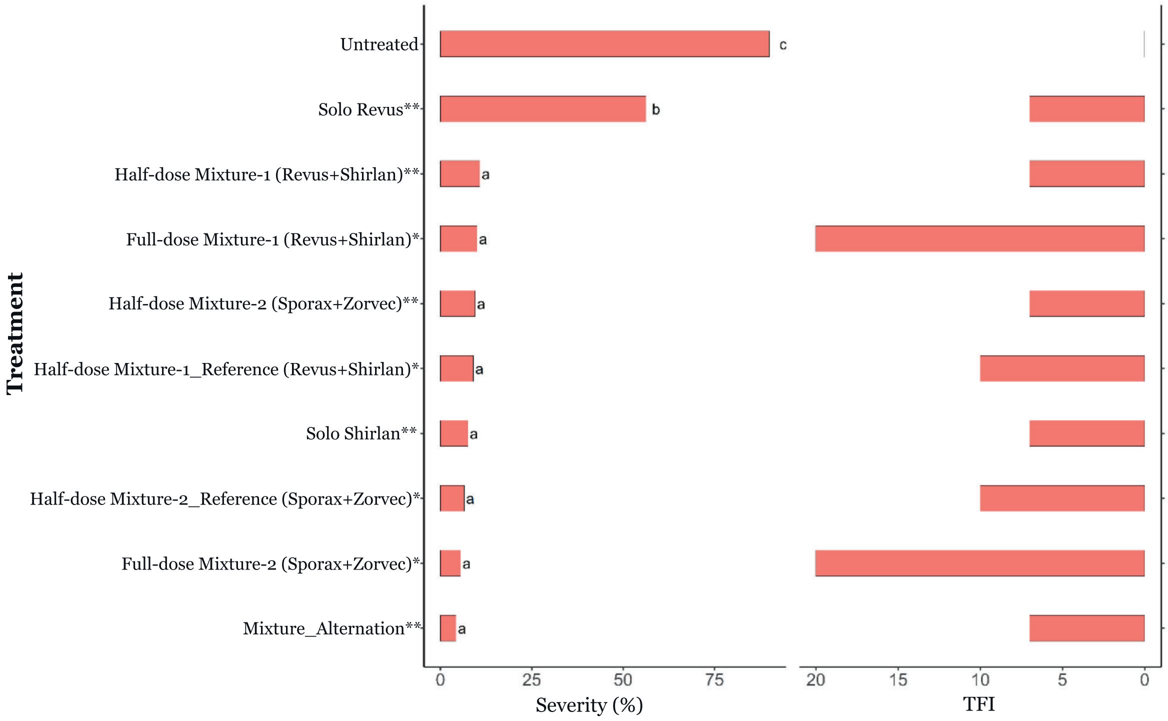

Figure 1. Late blight severity (Severity (%)) and treatment frequency index (TFI) of fungicide anti-resistant strategies (Treatment). The treatments marked with * were sprayed at a fixed dosage of fungicides, while those that are marked with ** were sprayed with variable dosages according to the BlightManager Decision Support System (DSS). All treatments were only sprayed when BlightManager DSS identified a late blight risk period. Bars (disease severity) with the same letters are not statistically significant and vice versa according to Tukey HSD test (α= 0.05). The active ingredients in the fungicides are as follows: Revus contains 250 g/l mandipropamid, Shirlan (Shirlan Ultra) contains 500 g/l fluazinam, Sporax contains 605 g/l propamocarb and Zorvec (Zorvec Enicade) contains 100 g/l oxathiapiprolin.

Comparison of starch yield from the different anti-resistant strategies

Figure 2 shows the starch yield in the different anti-resistant strategies. All strategies resulted in a significantly higher starch yield compared with the untreated control. The solo Revus was the fungicide strategy that recorded the lowest starch yield, and this also differed significantly from the other fungicide strategies. The full-dose mixture of Zorvec Enicade and Sporax had the highest starch yield. The starch yield of the full-dose mixture of Zorvec Enicade and Sporax was not different statistically from the other fungicide strategies except the solo Revus and Shirlan Ultra.

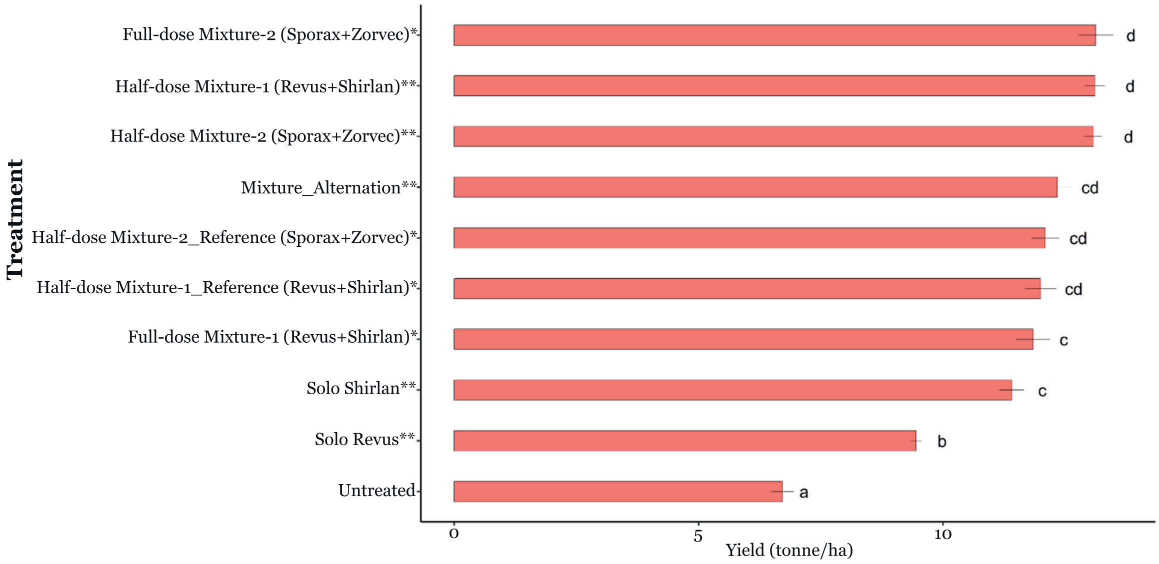

Figure 2. Starch yield (tonne/ha) of fungicide anti-resistant strategies (Treatment). The treatments marked with * were sprayed at a fixed dosage of fungicides, while those that are marked with ** were sprayed with variable dosages according to the BlightManager Decision Support System (DSS). All treatments were only sprayed when BlightManager DSS identified a late blight risk period. Bars (disease severity) with the same letters are not statistically significant and vice versa according to Tukey HSD test ($\alpha = 0.05$). The active ingredients in the fungicides are as follows: Revus contains 250 g/l mandipropamid, Shirlan (Shirlan Ultra) contains 500 g/l fluazinam, Sporax contains 605 g/l propamocarb and Zorvec (Zorvec Enicade) contains 100 g/l oxathiapiprolin.

Discussion

In this study, we demonstrate the potential to effectively manage late blight even in the presence of fungicide-resistant *P. infestans* populations. The use of solo Revus failed to provide adequate control due to the presence of the EU43 *P. infestans* genotype at the trial sites. Moreover, sequencing of late blight samples for the mutation conferring resistance to mandipropamid revealed a high number of resistant mutants in the solo Revus plots (data not shown).

Our findings show that fungicide mixtures offer effective late blight control. More importantly, reduced dosages of these mixtures can still achieve strong disease suppression. While full-dose mixtures were effective, they led to excessive fungicide use. In contrast, reduced-dose mixtures significantly lowered the TFI without compromising disease control or starch yield. Although mixtures generally provided good control, the combination of mixture and alternation strategies resulted in even better disease suppression. This suggests that an integrated anti-resistance strategy offers superior control compared with using a single approach. While half-dose mixtures were generally effective, further reducing the dosage – such as applying 50% of a half-dose mixture under low infection pressure – led to additional reductions in fungicide use without compromising disease control or starch yield. In fact, the lowest TFI, measured at 7 (representing a 65% reduction in fungicide use compared with the strategy with the highest TFI – 20), was only achieved when the dosage of half-dose mixtures was further adjusted based on infection pressure.

In conclusion, this study demonstrates that fungicide mixtures consistently reduced disease severity. Notably, reduced-dose mixtures were highly effective in minimising late blight incidence while also reducing fungicide usage. These half-dose mixtures used at least 50% less fungicide compared with full-dose treatments.

Acknowledgements
The work was funded by the Danish Environmental Protection Agency's Pesticide Research Programme (Grant no. 2022-89507) as part of the Potato-FRAS project. We are grateful to Hans Henning Hansen for his support in the field trial.

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VIII The fate of rattail fescue (*Vulpia myuros* L.) emerging in the spring: Investigation of differences in vernalisation requirements

Peter Kryger Jensen

Rattail fescue (*Vulpia myuros* L.) is an important weed in winter cereals and especially in grass seed production. The seed size makes it almost impossible to separate the seeds from a number of important cultivated grasses. Chemical weed control options in grass seed crops are very limited, and this makes integrated approaches both necessary and important in order to fulfil the quality requirements. Under Danish conditions, rattail fescue needs vernalisation by short days to become reproductive and set seed. Establishing grass seed crops in the spring has therefore become a method to reduce rattail fescue contamination of the grass seed crop. Rattail fescue plants germinating in the spring do not become vernalised in the year of emergence, but the fate of the plants is not clear. In this study, the fate of spring-germinating plants was monitored to see if the plants can survive the winter and set seed in the following season. The project further studied if there are differences in vernalisation requirements between Danish populations of rattail fescue.

Materials and methods

The project included two activities.

Activity 1: Fate of spring-emerging rattail fescue plants.

The fate of spring-emerging rattail fescue plants was investigated in field trials at Aarhus University (AU) Flakkebjerg (55˚19´N, 11˚24´E) for three years. In five different places at the experimental site, small 1 m^2 plots were marked close to the border of a field. In each plot, 10 cylinders with a depth of 5 cm and a diameter of 10 cm were placed and filled with sterilised soil. Ten seeds of rattail fescue were sown in each cylinder in April. Seeds used for the study came from the AU Flakkebjerg population of rattail fescue. No crops were sown in the marked plots, and the vegetation in the plots consisted of the naturally occurring plant species, typically perennial grasses. The rattail fescue plants were monitored in the second year with a counting of reproductive tillers.

Activity 2: Vernalisation requirements of Danish rattail fescue populations. The purpose of this activity was to investigate whether differences exist in vernalisation requirements between Danish rattail fescue populations. Four different populations were tested.

1. Flakkebjerg
2. Blans Østermark, Sønderborg
3. Drammelstrupvej, Ebeltoft
4. Vestvej, Nysted

Population 1 named Flakkebjerg was collected near AU Flakkebjerg. Seeds from the other three populations were collected at maturity in 2021 by colleagues from the Danish Advisory service. The vernalisation requirements were tested by sowing seeds of the four rattail fescue populations on approximately 1 February, 1 March and 1 April. The seeds, 25 per replicate, were sown in 5 l containers and kept in an unheated glasshouse until emergence began and then moved to an outside container site. The trial was replicated in 2022 and 2023. The populations were monitored with registration of tillering in June and July.

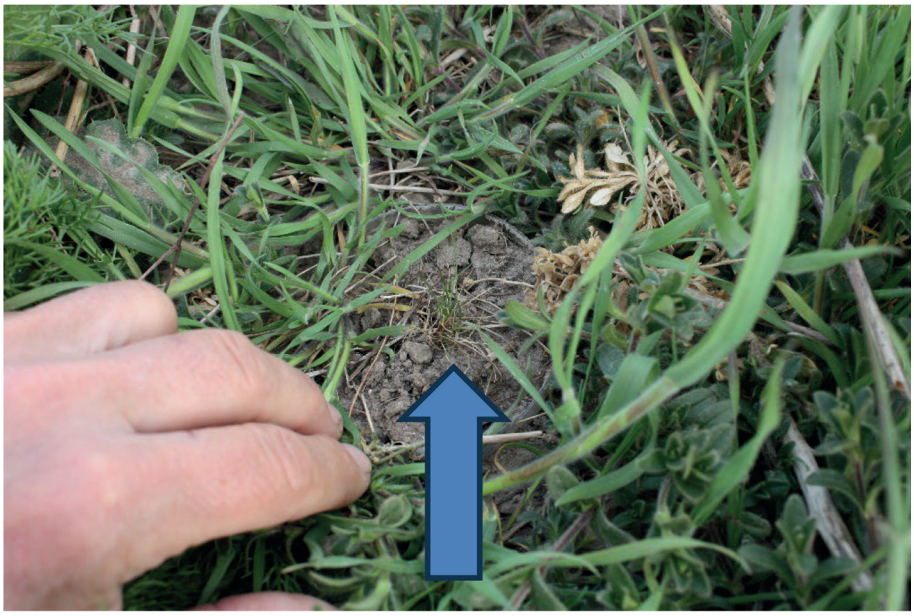
Results and discussion

Activity 1: Fate of spring-emerging rattail fescue plants.
The total number of tillers on rattail fescue plants each year is shown in Table 1.

Table 1. Total number of reproductive tillers of rattail fescue counted in 50 cylinders (five plots with 10 cylinders each) for three years.

Year	Total number of tillers
2022	2
2023	11
2024	9 (7 tillers on one plant)

The number of plants surviving in each cylinder could not be counted as it was not possible to separate the plant material without the risk of disturbing/destroying some plants. The rattail fescue plants generally desiccated during the winter, and growth in the spring started late compared to the other vegetation in the plots. An example is shown in the photo below taken at the beginning of May 2023.



Rattail fescue plant on 4 May 2023.

The late growth start meant that the rattail fescue plants were susceptible to competition and that a well-established crop would have an advantage. It was also the impression that the number of reproductive tillers in the plots was inversely related to the amount of vegetation in the plots.

Activity 2: Vernalisation requirements of Danish rattail fescue populations.
The three sowing times were based on experience from earlier studies, showing that plants from the Flakkebjerg population established from the earliest sowing on 1 February produced plants with seed-bearing tillers at the normal time in June, whereas plants emerging at the two late sowing times did not produce seed-bearing tillers in July. The observed growth stage (GS) of plants during the season is shown in Table 2 (year 2022) and Table 3 (year 2023). The observations of all four populations of rattail fescue in both years showed that there were only very minor and inconsistent differences between the four populations. As there were only minor differences between populations sown at the same time, the tables only show differences according to sowing time. In 2022, plants from population 2 (Blans Østermark, Sønderborg) were at a larger growth stage late in the season (September and October). In 2023, plants from the second sowing date, 3 March 2023, of population 3 from Ebeltoft had a slightly higher GS on 30 June than the other populations. These two differences between populations were the only ones observed during the two study years.

Table 2. Growth stage (GS) of rattail fescue plants sown at three separate times. The growth stage given is the maximum GS observed according to the Biologische Bundesanstalt, Bundessortenamt und CHemische Industrie (BBCH) scale. Year 2022.

	Registration date				
Sowing date	31 May	6 July	16 August	1 September	5 October
27-01-2022	55-57	89-93	93	93-85	95-99
04-03-2022	43-45	49-51	61-63	63-65*	75-85*
30-03-2022	35-37	39-41	43-47	43-49	51-53

*The high GS refers to population 2, whereas the three other populations have the low GS.

Table 3. Growth stage (GS) of rattail fescue plants sown at three separate times. The growth stage given is the maximum GS observed according to the Biologische Bundesanstalt, Bundessortenamt und CHemische Industrie (BBCH) scale. Year 2023.

	Registration date		
Sowing date	8 June	30 June	17 August
31-01-2023	33-51	71	89
03-03-2023	29	29-55*	63
03-04-2023	29	29	63

*GS 55 for population 3 from Ebeltoft. GS 29 for the other three populations.

Only the early established plants of all populations formed reproductive tillers with seeds during June and July. Plants established from sowing at the beginning of March or April did not set seed-bearing tillers in July, but some reproductive tillers were registered in the autumn following the sowing around 1 March. Such tillers will typically be destroyed during harvest. The observation that rattail fescue under Danish conditions requires a short-day vernalisation therefore seems to be general for Danish populations of rattail fescue.

Conclusion

Rattail fescue germinating and emerging together with spring-established crops does not set reproductive tillers in the first year. This study showed that spring-emerging plants to some degree survive the winter but are totally desiccated. Growth in the spring is therefore delayed compared to for example grass seed crops, and plants have a low competitive ability. Some plants are, however, able to produce reproductive tillers.

Based on a test of seeds from four different populations of rattail fescue, vernalisation requirements can be considered a general characteristic for Danish rattail fescue populations.

Rattail fescue from four different populations in Denmark. The photo shows the two late sowing times. The photo was taken on 16 August 2023 and none of the populations had developed normal reproductive tillers.

Acknowledgements

The investigation was financed by the Danish Seed Levy Fund (Frøafgiftsfonden).

IX List of chemicals

Fungicides and adjuvants		
Name	Active ingredients	Gram /l or kg
Agropol	Adjuvant	-
Amistar	Azoxystrobin	250
Ascra Xpro	Prothioconazole + bixafen + fluopyram	130 + 65 + 65
Balaya = Revycare	Mefentrifluconazole + pyraclostrobin	100 + 100
BAS 768 00F	Revysol + sulphur	600 + 25
BAS 831 00F	Fluxapyroxad + metyltetraprole	40 + 40
Bion 50 WG	Acibenzolar-S-methyl/benzothiazole	500
Charge	Chitosan	30
Comet Pro	Pyraclostrobin	200
Daxur	Mefentrifluconazole + kresoxim-methyl	100 + 150
Delaro Forte	Prothioconazole + trifloxystrobin	175 + 150
Elatus Era	Azoxystrobin + benzovindiflupyr	30 + 15
Elatus Plus	Benzovindiflupyr	100
Flexity	Metrafenon	300
Folicur EW 250	Tebuconazole	250
Folicur Xpert	Tebuconazole + prothioconazole	160 + 80
Folpan 500 SC	Folpet	500
Greteg	Difenoconazole	250
Greteg Star	Azoxystrobin + difenoconazole	125 + 125
Imtrex	Fluxapyroxad	62.5
Innox	Prothioconazole	250
Input Triple	Spiroxamine + prothioconazole + proquinazid	200 + 160 + 40
Iodus	Laminarin	45
Juventus 90	Metconazole	90
Lalstop G46 WG	*Clonostachys rosea*	1000000000 CFU/kg
Navura	Mefentrifluconazole + prothioconazole	50 + 100
Phosphonate	Phosphonic acid	504
Pictor Active	Pyraclostrobin + boscalid	250 + 150
Polyversum	*Pythium oligandrum* M1	1000000000 CFU/kg
Priaxor	Pyraclostrobin + fluxapyroxad	150 + 75
Proline EC 250	Prothioconazole	250
Propulse SE 250	Fluopyram + prothioconazole	125 + 125
Prosaro EC 250	Prothioconazole + tebuconazole	125 + 125
Questar	Fenpicoxamid	100
Revus	Mandipropamid	250
Revycare	Mefentrifluconazole + pyraclostrobin	100 + 100
Revysol	Mefentrifluconazole	100
Revystar XL	Mefentrifluconazole + fluxapyroxad	100 + 50
Revytrex	Mefentrifluconazole + fluxapyroxad	66.7 + 66.7

Fungicides and adjuvants		
Name	**Active ingredients**	**Gram /l or kg**
Revytur	Mefentrifluconazole + sulphur	25 + 600
Serenade ASO	*Bacillus amyloliquefaciens*	7131 x 1012 CFU/l
Shirlan Ultra	Fluazinam	500
Silwet Gold	Adjuvant	-
Soratel	Prothioconazole	250
Sorrento	Adjuvant	-
Sporax	Propamocarb	605
Talius EC	Proquinazid	200
TF2	Biologicals	-
Thiopron	Sulphur	825
Thore	Bixafen	125
Univoq	Prothioconazole + fenpicoxamid	100 + 50
V1P	Biologicals	-
Vegas	Cyflufenamid	51.3
Verben	Proquinazid + prothioconazole	50 + 200
Vertipin	Sulphur	700
Xemium + Dev cpd	Fluxapyroxad + metyltetraprole	90 + 90
Zorvec Enicade	Oxathiapiprolin	100

About DCA

DCA - Danish Centre for Food and Agriculture is the entrance to research in food and agriculture at Aarhus University (AU).

The Centre comprises AU departments with food and agricultural science activities. These are primarily Department of Agroecology, Department of Animal Science, Department of Food Science, Centre for Quantitative Genetics and Genomics, and parts of Department of Engineering.

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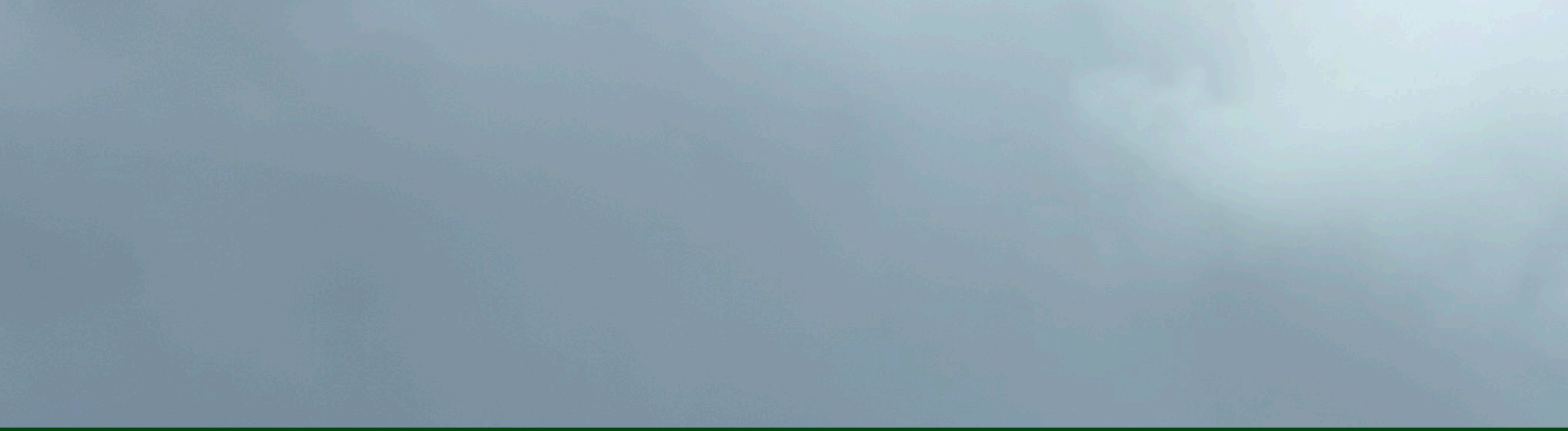
DCA also publishes a report series, which primarily communicates policy support tasks from DCA to the Ministry of Food and Environment of Denmark. Further publications include reports that communicates knowledge from research activities. The reports may be downloaded free of charge at the DCA website: dca.au.dk.

Newsletters
A Danish and English DCA newsletter communicate knowledge within agricultural and food research, including research results, advice, education, events and other activities. You can register for the free newsletter at dca.au.dk.



SUMMARY

This publication contains results from 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 laboratory testing and greenhouse and semi-field trials are 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