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Variation in Fungicide Application Windows for Fusarium Head Blight Management Across Wheat Production Environments

Ismaeil Musbah Al-Far
Department of Plant Pathology, Faculty of Agriculture, Bani Walid University, Bani Walid, LIBYA.

Corresponding Author: esmailalfar@bwu.edu.ly

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ABSTRACT

Fusarium head blight reduces wheat yield and can contaminate grain with deoxynivalenol. Fungicide timing affects both outcomes, but useful application windows differ among production environments. This paper examines published experiments from the United States, Canada, Italy, and other supporting research. A focused evidence synthesis compared application stages, wheat classes, cultivar resistance, moisture conditions, and measured outcomes. Published treatment effects were retained within their original studies. No new field observations or pooled estimates were created. Early flowering remained the most dependable reference stage across the evidence. However, several experiments supported useful applications during the following days. Seven experiments in Ohio and Illinois reported comparable toxin suppression from flowering and several later applications. A larger network analysis found stronger average disease suppression at flowering than five to seven days later. Saskatchewan durum trials supported applications through the end of flowering under favorable disease conditions. Nebraska experiments showed that irrigation and seasonal moisture changed disease pressure and treatment performance. Italian research further showed that crop stage alone could poorly represent the timing of infection. These differences explain why a single calendar interval cannot describe every wheat field. Cultivar resistance, local forecasts, crop development, and grain testing should guide interpretation of timing research. Delayed treatment can preserve useful control when the main target is missed. However, its value depends on the field environment and the outcome being protected. The evidence supports locally adjusted flowering windows within an integrated disease management program.

Keywords- wheat; Fusarium head blight; fungicide timing; anthesis; deoxynivalenol; cultivar resistance; production environment.

I. INTRODUCTION

Fusarium head blight, called FHB here, damages wheat heads and reduces the value of harvested grain. *Fusarium graminearum* is a major cause of FHB in wheat. Its effects include fewer healthy kernels, lower grain weight, and contamination with fungal toxins. Deoxynivalenol, shortened to DON, is a major concern in affected wheat. Disease management therefore needs to protect grain quality alongside yield (McMullen et al., 2012).

Fungicide application is one part of this management. Its success depends partly on when the wheat head receives protection. Flowering, also called anthesis, provides the usual reference stage. However, rain, uneven crop development, and limited field access can prevent treatment at the intended time. Published timing experiments help explain what remains possible after that target is missed (D'Angelo et al., 2014).

An application window describes the period when treatment can provide useful disease or toxin suppression. The best treatment day and the useful window are different questions. A later application may help, even when an earlier application gives stronger average control. This distinction matters when interpreting results from different locations.

The phrase early flowering also needs a clear definition. A head begins flowering when fresh yellow anthers appear near its middle. A field contains many heads that reach this stage at different times. Figure 1 shows flowering, a blighted

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head, and damaged kernels. The symptom photographs come from Mueller et al. (2024). Field assessments should describe the proportion of main stems flowering (Bish et al., 2026).



Figure 1 Photographs show early flowering (A), a blighted head (B), and damaged kernels (C).

Table 1 Growth stage terms used in the comparison

Term	Stage reference	Meaning
Heading complete	BBCH 59	The head is fully emerged. Flowering has not necessarily begun.
Early flowering	BBCH 61	The first anthers become visible.
Mid flowering	BBCH 65	Flowering has reached about halfway on the head.
End of flowering	BBCH 69	Flowering is complete. Dry anthers may remain.
Days after anthesis	Author defined	The reference flowering observation must remain stated.

Growth stages describe crop development more clearly than calendar dates. However, they cannot fully describe local disease pressure. Weather and crop conditions also affect whether a treatment opportunity becomes useful. Therefore, this paper compares timing within the environment reported by each study. Its main question concerns how these conditions change the practical value of delayed applications.

II. MATERIALS AND METHODS

2.1 Review approach and source selection

This paper presents a focused evidence synthesis of published experiments. It does not report a newly conducted field experiment. Searches were completed on Feb 28, 2026. Sources included PubMed, SciSpace, publisher websites, university repositories, and public agricultural research reports. Search phrases combined wheat, Fusarium head blight, fungicide timing, anthesis, DON, irrigation, and cultivar resistance.

Studies were selected when their public records described wheat, fungicide timing, and relevant disease or grain outcomes. Preference was given to replicated field experiments and analyses covering several environments. Public university trials provided additional practical examples. Studies on barley and rye were excluded from the wheat comparison. Supporting experiments were retained when they clarified differences between visible disease and toxin outcomes.

This was a targeted review without a registered protocol. It did not attempt an exhaustive systematic search. Therefore, no screening flowchart or complete publication count is claimed. Public abstracts supported some comparisons where complete articles were unavailable. Full text was examined for the openly accessible Italian experiments. Conclusions were restricted to results available in the consulted source material Mayor .

2.2 Information extracted from experiments

The comparison recorded study location, trial years, wheat class, treatment timing, and measured outcomes. Cultivar resistance and irrigation were recorded when reported. Important outcomes included FHB index, damaged kernels, DON concentration, grain yield, and test weight. Disease severity and disease incidence were kept separate. These measures describe different parts of the disease response.

Days after anthesis were retained as reported by each author. They were not converted into exact growth stages. Flowering progresses at different speeds across environments. A fixed conversion could therefore misclassify treatments. Experiments using early anthesis were also distinguished from experiments using mid flowering. This prevents an apparent timing difference created only by different starting definitions.

2.3 Comparison and interpretation

Published percentage control values were transcribed without combining independent studies. Their reference treatments remain stated beside the values. Percentage control describes reduction relative to the stated comparison. It does

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not describe the final toxin concentration. Reported statistical conclusions were retained without adding new significance tests.

No original plot records, standard errors, or treatment variances were reconstructed. No new meta-analysis was performed. Earlier experiments may also contribute to later published syntheses. Their trial counts were therefore never added into one total. Table 2 identifies the main experimental evidence. Figure captions identify source graphics and their download locations. Figure 3 converts published log response ratios into percentage reductions. Its calculation uses one minus the exponential of each ratio, multiplied by 100. The plotted values are derived model estimates, rather than new field observations. All scientific citations use author and year within the text.

III. RESULTS FROM PUBLISHED EXPERIMENTS

The selected experiments covered several wheat classes and production settings. Their results support flowering as the main reference stage. They also show useful flexibility after flowering begins. However, the size of this flexibility changed with the study and measured outcome. Table 2 presents these differences without treating separate experiments as directly comparable replications.

Table 2 Main published experiments and supporting comparisons

Study and setting	Evidence base	Timing result or role
D'Angelo et al. (2014) Ohio and Illinois	Seven experiments 2011 to 2013 Soft red winter wheat	Useful disease and DON suppression continued through six days after early anthesis.
Paul et al. (2018) United States	Network analysis 19 years of trials Spring and winter wheat	Anthesis gave stronger average disease control than applications five to seven days later.
Bolanos-Carriel et al. (2020) Nebraska	Resistance, timing, and water environment comparison Hard red winter wheat	Six days after anthesis remained useful. Twelve days was least effective.
Singh et al. (2021) Saskatchewan	Three locations 2016 to 2018 Durum wheat	Flowering stages performed similarly under favorable disease conditions.
González-Domínguez et al. (2021) Ravenna, Italy	Stage trials during 2013 to 2015 Further timing trials during 2017 and 2018	Crop stage alone did not fully explain treatment performance.
Haidukowski et al. (2012) Italy	Twenty experiments Five growing seasons Common and durum wheat	Single stage evidence showed flowering treatment efficacy and variation between wheat classes.

Note. These sources overlap in purpose and may overlap in underlying trials. Their counts are not additive.

The table separates direct timing experiments from supporting research. A study testing several application stages can describe timing differences. A study using only one stage can describe product or environmental responses at that stage. It cannot identify the best stage by itself. This distinction is especially important for the Italian flowering trials.

Published syntheses provide broader averages than individual trials. However, those averages describe their underlying study populations. They cannot guarantee a particular response in one field. Equally, one favorable delayed application cannot establish a universal recommendation. The following sections examine each main comparison before drawing broader conclusions.

3.1 Flowering and later applications in soft red winter wheat

D'Angelo et al. (2014) conducted seven experiments in Ohio and Illinois during 2011 through 2013. The research compared early anthesis with several later application times. Treatments included metconazole and prothioconazole plus tebuconazole. Measured outcomes included FHB index, Fusarium damaged kernels, and DON. Table 3 reproduces selected percentage control values from the published abstract.

Table 3: Selected control values from the Ohio and Illinois experiments

Application timing	FHB index reduction (%)	DON reduction (%)
Early anthesis	56	50
Two days after anthesis	69	54
Four days after anthesis	62	52
Six days after anthesis	62	48

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The highest listed disease control occurred two days after anthesis. However, later treatments generally did not improve DON suppression beyond the anthesis treatment. Most postanthesis comparisons remained statistically similar to anthesis. The study therefore supported useful control through six days after the reference stage (D'Angelo et al., 2014).

These findings require careful reading. The highest numerical value does not always identify a reliably superior treatment. Disease and toxin outcomes may also rank the same treatments differently. A grower concerned mainly with DON cannot choose timing from disease percentages alone. The reported statistical comparisons provide necessary context for the numerical values.

The study offers practical evidence when wet weather delays field access. Missing early anthesis did not eliminate all treatment value in these experiments. Nevertheless, the results do not establish six days as a fixed deadline everywhere. Their reference was early anthesis under the reported winter wheat conditions. Other environments require their own supporting evidence.

There is also a difference between delay and planned postponement. Evidence supporting a useful later treatment can help manage an unexpected delay. It does not automatically justify waiting when a suitable flowering opportunity exists. This interpretation becomes clearer when the individual trials are compared with broader network results.

3.2 Timing effects across spring and winter wheat

Paul et al. (2018) analyzed 19 years of fungicide trial data using network meta-analysis. Their comparison included heading, anthesis, and applications five to seven days after anthesis. Both metconazole and prothioconazole plus tebuconazole were evaluated. Table 4 presents the reported average FHB index reductions for flowering and later applications.

Table 4 Average disease control in the published timing network

Active ingredient	At anthesis (%)	Five to seven days later (%)
Metconazole	52.2	45.9
Prothioconazole plus tebuconazole	51.5	41.3

Heading applications provided less than 33% average disease control for either product. Anthesis applications produced stronger average index suppression than the delayed treatments. Those timing differences were statistically supported in the published analysis. DON control also varied with wheat type. Applications at or after anthesis performed better against DON in spring wheat (Paul et al., 2018).

The network findings do not invalidate the Ohio and Illinois experiments. A broad average and a smaller regional experiment answer different questions. The regional study identifies outcomes under its tested conditions. The network analysis describes the average across a much wider evidence base. Both support a useful delayed option, while the network favors anthesis overall.

These results also show why a useful window should not imply equal performance throughout that window. Treatment may remain beneficial after the average optimum has passed. The decline may be modest in one setting and larger in another. A recommendation should distinguish the preferred target from the available later opportunity.

Figures 9 and 10 provide additional graphs of the published timing results. An earlier synthesis also found substantial differences among products and wheat classes (Paul et al., 2008). This matters because timing cannot compensate for an unsuitable active ingredient. Comparing treatment stages requires attention to the products being tested. Otherwise, a product difference may be incorrectly described as a timing difference.

3.3 Rainfed and irrigated winter wheat

Bolanos-Carriel et al. (2020) compared fungicide timing, cultivar resistance, and production environment in hard red winter wheat. Early anthesis provided the strongest overall treatment response. An application six days later remained broadly comparable, although somewhat weaker. Application twelve days after anthesis was least effective.

The moderately resistant cultivar Overland had lower disease, damaged kernels, and DON than susceptible Overley. Irrigated conditions increased these outcomes and reduced yield relative to rainfed conditions. These environmental differences were greater during the wetter season. The trial shows that moisture conditions can change both background disease pressure and observed treatment performance (Bolanos-Carriel et al., 2020).

These results should not be converted into one rule for every irrigated field. Irrigation systems differ in how they wet wheat heads. Rainfall, soil conditions, and crop development also differ. The relevant lesson is to evaluate water management alongside the flowering stage. An irrigation label alone cannot describe the whole production environment.

Figure 2 summarizes the reported contrast between irrigated and rainfed wheat. It shows directional differences, without assigning numerical means. The diagram describes the Nebraska comparison reported by Bolanos-Carriel et al. (2020). It does not define an irrigation effect for every field.

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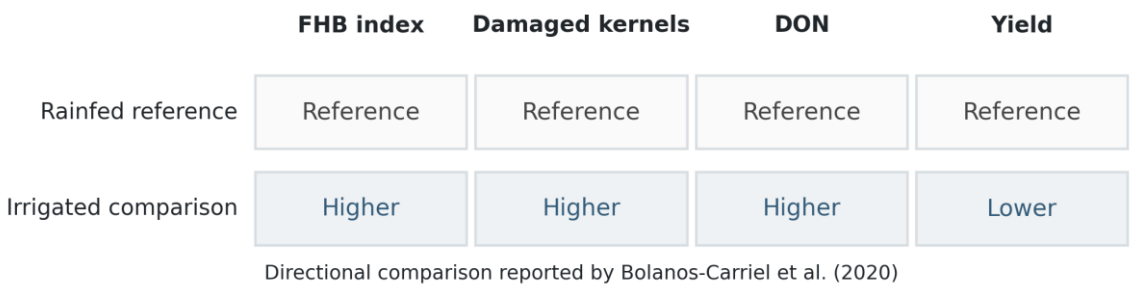


Figure 2 The diagram shows reported directions of change. It contains no numerical treatment means. Source: Redrawn from Bolanos-Carriel et al. (2020).

Weather records can help explain why the same nominal stage produces different outcomes between seasons. However, association alone cannot identify which weather event caused a treatment difference. That question requires suitable trial design and infection observations. The strongest interpretation combines recorded weather with measured crop development and disease outcomes.

3.4 Durum wheat and the meaning of late flowering

Singh et al. (2021) studied durum wheat at three Saskatchewan locations during 2016 through 2018. Treatments covered heading, several flowering stages, and early grain development. Under conditions favorable for FHB, applications from early through late flowering produced similar outcomes. These outcomes included disease index, damaged kernels, DON, and yield.

Mid flowering performed better than other single timings during seasons with low disease severity. Two applications did not consistently improve disease and toxin outcomes beyond the mid flowering application. The findings supported treatment through flowering under the tested high risk conditions (Singh et al., 2021).

The Canadian result should be described through its measured stages. End of flowering is a crop stage, rather than a universal number of days. Warm and cool seasons can reach it at different intervals. Comparisons with winter wheat therefore need a shared starting definition. A simple day count may hide meaningful differences in crop development.

Italian research provides another test of stage based interpretation. González-Domínguez et al. (2021) compared applications across heading and flowering in durum wheat. In their first experiment, severity and DON reductions remained below 50%. Differences among application stages were not significant. Figure 3 shows transformed model estimates for the DMI treatment group. DMI means demethylation inhibitor, a fungicide group.

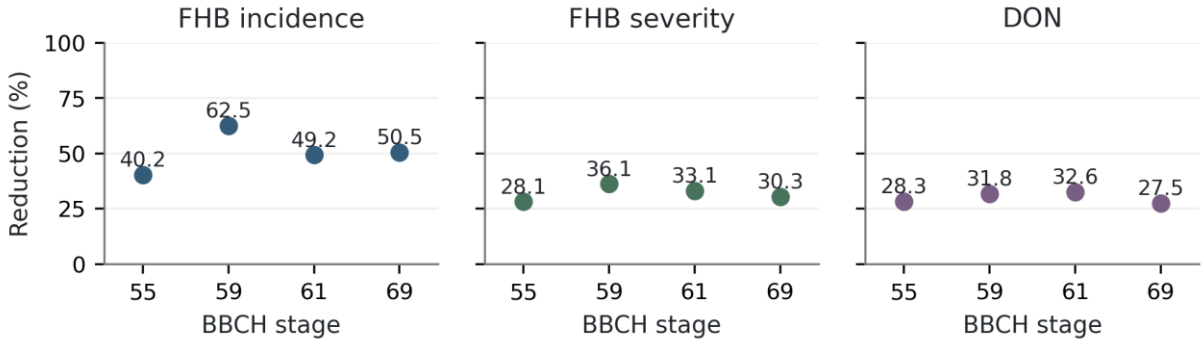


Figure 3 DMI treatment estimates are shown for incidence, severity, and DON. Uncertainty intervals are not plotted. Source: Calculated from González-Domínguez et al. (2021)

Percentage reduction equals 100 multiplied by one minus the exponential of the published log. That result does not prove timing never matters. It shows that stage differences alone did not explain treatment performance in that experiment. The same study also examined treatment timing in relation to infection. Its results supported closer attention to when protective activity overlaps infection. This helps explain variation within the same flowering stage (González-Domínguez et al., 2021).

3.5 Flowering treatments in common and durum wheat

Haidukowski et al. (2012) reported twenty Italian field experiments across five growing seasons. Their study compared fungicides applied at the beginning of anthesis. It included common wheat and durum wheat. Prothioconazole based treatments reduced disease severity by 39% to 93%. Reported DON reductions ranged from 40% to 91%. These ranges describe observed variation, rather than guaranteed performance.

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The treatment response against DON and yield was generally stronger in common wheat. Figures 4 and 5 summarize the reported ranges and mean DON responses. The underlying studies used one flowering reference. They therefore support flowering treatment efficacy without locating the best application stage (Haidukowski et al., 2012).

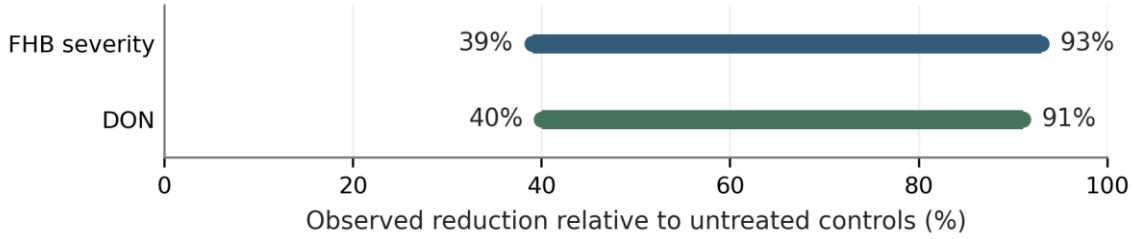


Figure 4 Ranges show observed disease and DON reductions. They are not confidence intervals. Source: Redrawn from Haidukowski et al. (2012)

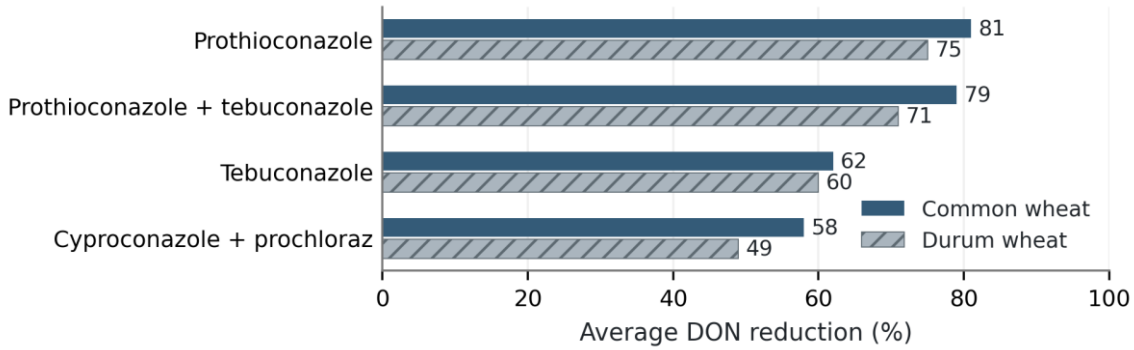


Figure 5 Bars show average DON reductions from the published trials. Bar heights alone do not establish statistical significance. Source: Redrawn from Haidukowski et al. (2012).

The response ranges show why one average can hide important differences. Similar products and growth stages do not ensure identical outcomes. Wheat class and seasonal conditions can change the observed response. Field conditions should therefore remain beside the treatment results.

3.6 Disease suppression and toxin suppression can differ

Visible disease and grain contamination are related, but they are not interchangeable outcomes. A treatment may reduce head symptoms without producing an equally large DON reduction. The reverse pattern is also possible. Timing comparisons therefore require more than one disease measure. Table 5 explains what each major outcome contributes.

Table 5 Outcomes that should remain separate in timing research

Outcome	What it describes	Main interpretation limit
Incidence	Proportion of heads affected	Does not describe symptom extent within affected heads.
Severity	Extent of affected tissue within heads	Its denominator must be defined by the study.
FHB index	Combined plot level disease burden	Scoring methods must be checked before comparison.
Damaged kernels	Visible kernel damage	Does not directly measure toxin concentration.
DON	Toxin concentration in sampled grain	Depends on representative sampling and the test method.
Yield	Harvested grain quantity	Does not establish grain acceptability.

Yoshida et al. (2012) tested application timing over two years under research conditions. Anthesis treatment was important for reducing visible FHB. A later treatment reduced grain mycotoxins without reducing disease severity. The study used thiophanate-methyl and a specific experimental setting. It does not establish a general late treatment recommendation for modern wheat programs.

Its main contribution is the separation of two management goals. Preventing early disease and limiting final toxin contamination may involve different biological periods. However, a result from one product cannot be transferred automatically to another. Product activity, crop stage, and experimental conditions must remain attached to the conclusion.

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Pirgozliev et al. (2008) also showed that protective treatment performance depended on timing relative to infection. Their winter wheat experiments linked disease and DON responses with the timing of fungicide protection. This supports interpretation beyond the crop stage alone. It does not provide a field method for observing every infection event.

For practical evaluation, grain testing remains necessary when toxin contamination is a concern. An attractive crop or a favorable disease score cannot establish the final DON concentration. Percentage reductions also need an absolute reference. A large proportional reduction can still leave substantial contamination when the untreated level is high.

This distinction changes how application windows should be reported. A study may support a later window for disease suppression. Its DON evidence may support a narrower or less certain window. Both findings should remain visible. Combining them into one general control rating can hide an important limitation.

3.7 Public field trials under low disease pressure

Public trials also help explain seasons when yield differences are small. Bish et al. (2020) reported Missouri research conducted during 2020 and 2021. Disease severity and DON were low during both seasons. Grain yields were statistically similar across the tested treatments. Figure 6 identifies the original 2021 yield chart.

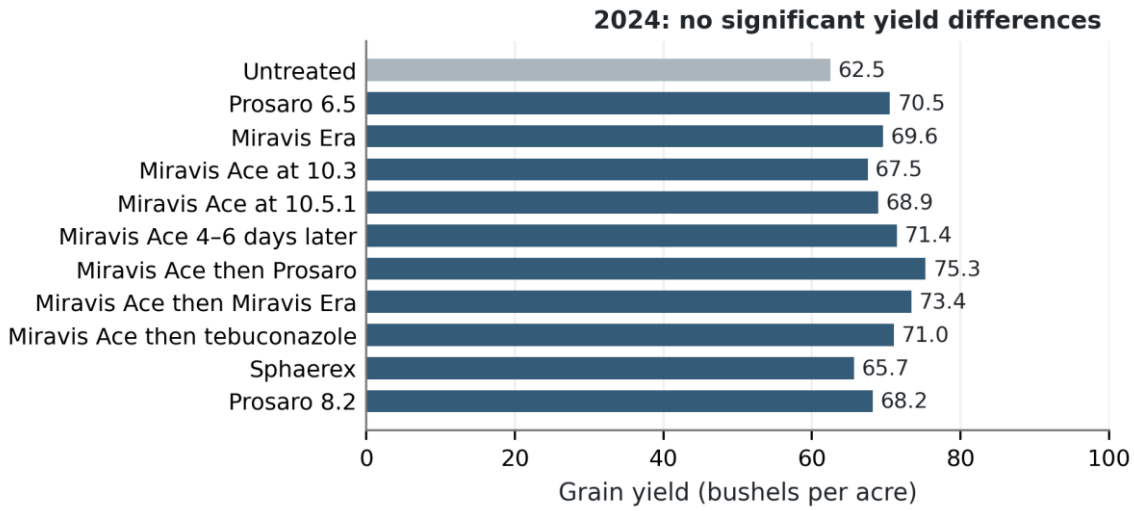


Figure 6 The 2021 yields were statistically similar under low disease pressure. Values are bushels per acre. 10.3 and 10.5.1 are Feekes stages. Later days follow Feekes 10.5.1. Prosaro rate labels follow the source

A low disease season tests a different situation from a severe outbreak. When disease damage is small, there may be little yield loss for fungicide treatment to prevent. Such a season can provide useful information about product performance under ordinary field conditions. It provides weaker evidence about the limits of protection during a major epidemic.

Statistically similar yields also require careful wording. They show that the experiment did not detect a supported treatment difference. They do not prove that all treatments are exactly equal. Trial size, field variation, and disease pressure influence the ability to detect differences. Practical conclusions should match the strength of the experiment.

The 2024 chart includes several products and application programs. Its bars should therefore be interpreted with the original treatment descriptions. A reader should not assign every yield difference to timing. Product choice and treatment sequence can also vary between bars. The original figure caption provides the necessary local context.

These trials show why a timing recommendation should not promise a yield increase every season. Treatment value depends partly on the damage that would occur without treatment. Grain quality may also matter when yield changes remain small. The relevant comparison should therefore include disease, toxins, yield, and treatment cost.

IV. DISCUSSION

4.1 Why published windows differ

The evidence supports a preferred flowering target with varying opportunities afterward. Differences arise partly because experiments measure different crop populations and weather conditions. They also use different reference stages. A delay measured from first flowering cannot be assumed equal to a delay measured from mid flowering.

Figure 7 identifies the Missouri chart for the following season. The two annual charts provide separate examples of low disease field conditions. They should not be interpreted as independent proof of equal timing performance everywhere. Their practical value lies in showing the limited yield separation observed in those specific trials.

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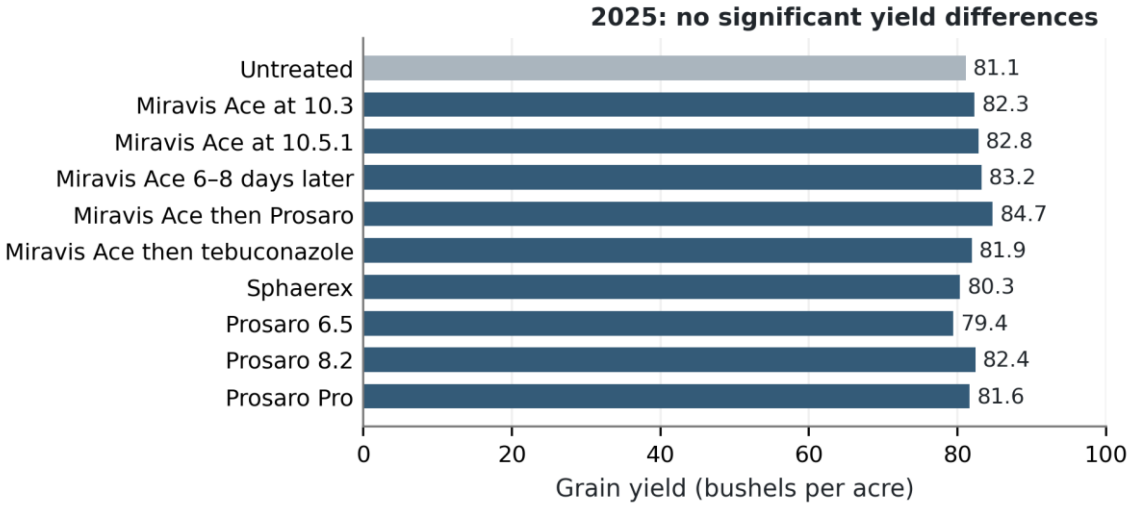


Figure 7 The 2022 yields were statistically similar under low disease pressure. Values are bushels per acre. 10.3 and 10.5.1 are Feekes stages. Later days are measured after Feekes 10.5.1

Weather based prediction research provides another part of the explanation. De Wolf et al. (2003) developed models using 50 location years across four states. Their results showed that weather around anthesis helped predict FHB epidemics. This established a basis for connecting the flowering stage with local weather information.

Shah et al. (2013) later evaluated 527 observations and included crop and weather information. Their models considered cultivar resistance, wheat type, and corn residue. Weather information improved prediction beyond these crop factors. The study supports combining field characteristics with weather, rather than using either alone.

Forecasts still describe probability across defined settings. They cannot guarantee whether a particular field will develop damaging disease. Their practical role is to support a timely decision while uncertainty remains. Waiting until disease becomes obvious can remove much of that decision time. Locally relevant forecasts are therefore most useful alongside direct crop staging.

4.2 Cultivar resistance and field history

Willyerd et al. (2012) combined evidence from more than forty trials across twelve U.S. states. A moderately resistant cultivar with fungicide treatment gave the strongest overall control. Disease index fell by 76%, and DON fell by 71%. The comparison was susceptible wheat without fungicide. Fungicide on susceptible wheat produced smaller reductions of 53% and 39%, respectively.

This evidence concerns integrated management at anthesis. It does not directly measure how resistance changes the length of a delayed application window. However, it shows why timing should be evaluated within the whole disease management program. A suitable cultivar can improve the starting conditions before application timing is considered.

Dill-Macky and Jones (2000) examined crop sequence and tillage during three seasons. Disease was greatest after corn and lowest after soybeans. The study supports considering field history when interpreting FHB pressure. Its results do not identify one tillage choice for every soil. Soil protection and local agronomic needs also matter.

Table 6 Interpretation of treatment opportunities across field situations

Field situation	Main concern	Interpretation supported by the evidence
Humid winter wheat	Sustained disease pressure	Target flowering. A short delay may retain useful protection.
Irrigated winter wheat	Head wetness and cultivar response	Evaluate water management alongside stage and resistance.
Durum wheat	Disease and grain quality	Some tested environments supported treatment through flowering.
Uneven flowering	Different stages among heads	Describe the field distribution before applying a day based rule.
Low disease season	Limited measurable damage	A small yield response cannot establish failure under epidemic conditions.

Table 6 presents a qualitative interpretation of the evidence. Its categories are discussion aids, rather than a validated prediction model. They contain no new numerical risk scores. A field may also fit more than one category. Local advice and direct observation remain necessary when choosing among competing treatment opportunities.

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Blandino et al. (2011) similarly found that agronomic conditions changed treatment responses in northwest Italy. Disease control, yield response, and DON reduction did not follow one identical pattern. These findings support recording the surrounding production conditions whenever timing results are compared. They also discourage assigning all variation to the application day.

4.3 Product choice and repeated applications

Timing works together with fungicide activity and effective head coverage. A product suited to leaf diseases may provide inadequate FHB suppression. Paul et al. (2008) found substantial differences among the tested triazole treatments. Their synthesis also showed considerable variation between experiments. Therefore, timing comparisons should identify the active ingredients clearly.

The U.S. Wheat and Barley Scab Initiative (USWBSI, 2020) publishes recent comparisons among fungicide programs. Figure 8 identifies its public DON comparison. It provides a public example of current research communication. It should not be used to extend the timing window of every listed product. The treatment descriptions and original comparison remain necessary.

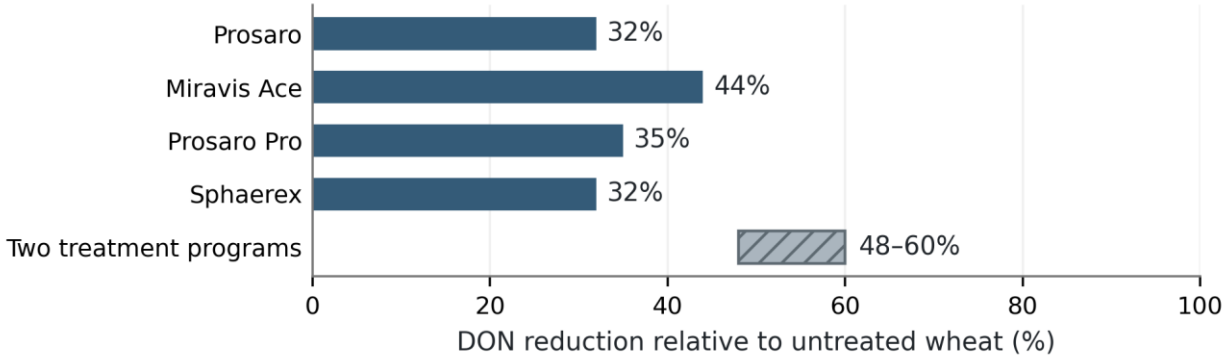


Figure 8 Bars show published DON reductions for single treatments. The two treatment range is not a confidence interval.

The USWBSI (2026) summary notes that some two treatment programs can further reduce FHB and DON. It also identifies uncertainty about when those programs become economical. This supports continued comparison under different disease conditions. It does not establish repeated applications as the best choice for every field.

Yield evidence also needs an economic setting. Paul et al. (2010) analyzed yield and test weight responses across many U.S. environments. Their work connected treatment response with disease intensity. For a practical decision, grain value, quality requirements, and application cost must also be considered. These factors can change without changing the biological treatment response.

Published research timings describe what was tested. They do not establish legal application timings in every country. Product registration and harvest restrictions remain product specific. A locally permitted treatment must fit those conditions. Research evidence can then help identify the most suitable opportunity within the permitted period.

V. STUDY LIMITATIONS

This review used a targeted search and selected publicly accessible evidence. It cannot establish that every relevant experiment was identified. English language sources and accessible records may have shaped the selection. Some comparisons relied on abstracts because complete articles were unavailable. Those studies were interpreted only through their reported public results.

The experiments differed in wheat class, cultivar, products, moisture conditions, and disease pressure. Several studies used managed disease challenge rather than ordinary natural exposure. Their treatment rankings may remain useful, but absolute outcomes can differ in commercial fields. These differences limit direct comparisons among published percentages.

The review also lacked a common set of original plot records. It therefore could not estimate a new average effect or uncertainty interval. Published syntheses may contain some experiments discussed separately here. Treating all reported trial counts as independent would overstate the evidence. No such combined count was calculated.

Most detailed evidence came from North America and Italy. The conclusions should therefore be transferred cautiously to other wheat regions. Local flowering patterns, weather, cultivars, and registered products may differ. This paper does not establish a separate application window for untested environments.

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VI. PRIORITIES FOR FURTHER RESEARCH

Future timing trials should use consistent flowering definitions and report the proportion of heads at each stage. They should retain disease, DON, yield, and quality as separate outcomes. Naturally affected fields across several seasons would improve practical interpretation. Weather records and field access delays would also help explain treatment opportunities.

Trials should distinguish a planned delay from an unavoidable delay. Economic comparisons should include quality discounts alongside yield changes. Sharing treatment means, uncertainty measures, and clear site descriptions would support stronger future syntheses. Research should also test whether regional advice remains suitable under changing crop development patterns.

VII. CONCLUSIONS

Flowering remains the most dependable reference for fungicide application against FHB. Published experiments also support useful later applications in several wheat environments. The strongest evidence concerns a limited extension after early anthesis or through flowering. It does not establish one universal interval for every field.

Broader analyses favor anthesis on average, while some regional trials show comparable control from later treatments. Moisture, wheat class, cultivar resistance, and measured outcomes help explain these differences. Disease suppression must also be separated from DON suppression. A useful treatment window should state which outcome the evidence supports.

The practical response is to combine accurate crop staging with local disease information and suitable fungicides. Cultivar resistance and field history improve the wider management program. Grain testing remains necessary when toxin contamination matters. Delayed treatment can retain value, but its expected benefit must remain tied to the tested conditions.

Data availability. All numerical values come from the publications cited in the text and tables. No new field dataset was generated.

TIMING GRAPHS

These graphs present selected values already reported in Tables 3 and 4. Figure 9 compares disease and toxin responses within the Ohio and Illinois experiments. Figure 10 compares published average disease responses from the wider timing network. The graphs remain separate because their study populations and statistical methods differ. Their bars should not be combined into one new treatment ranking.

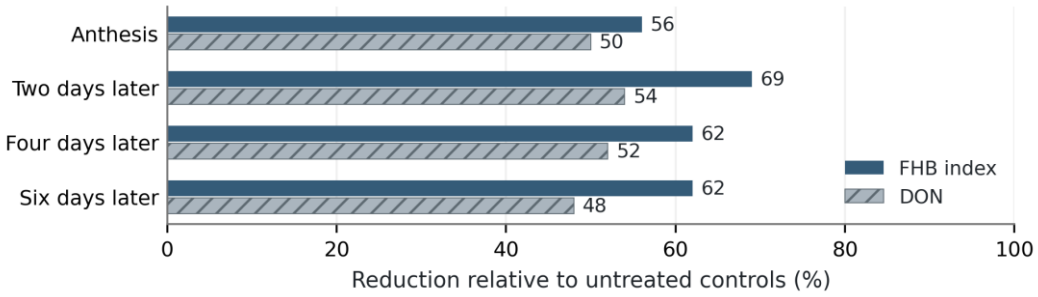


Figure 9 Published control percentages compare FHB index and DON. Uncertainty intervals are not shown. Source: Redrawn from D'Angelo et al. (2014).

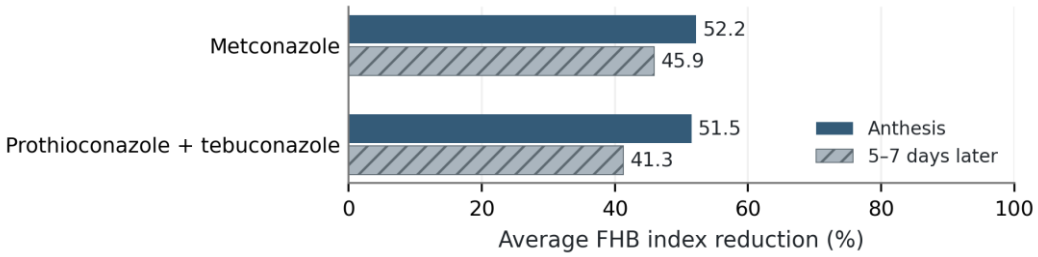


Figure 10 Published network estimates compare anthesis and later applications. Values represent FHB index reduction relative to untreated controls. Source: Redrawn from Paul et al. (2018), published abstract.

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