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Agreement Between Fusarium Head Blight Suppression and Mycotoxin Reduction Under Fungicide Treatment in Wheat

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التوافق بين كبح لفحة السنبلة بالفيوزاريوم وتقليل السموم الفطرية تحت المعاملة بمبيدات الفطريات في القمح

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Abstract:
Fusarium head blight reduces wheat yield and can contaminate grain with mycotoxins, especially deoxynivalenol. Fungicides can reduce both outcomes, but their effects do not always match. This study examined agreement between disease suppression and toxin reduction using publicly available research. A targeted literature review covered field experiments, research reviews, and published meta analyses. Numerical comparisons used reported treatment effects and their original control groups. Agreement was examined through response direction, treatment ranking, and differences between percentage reductions. No new field experiments or pooled statistical tests were performed. Published evidence showed positive relationships between visible disease and deoxynivalenol, with considerable variation among studies. One major analysis reported disease reductions of 32–52%, compared with toxin reductions of 12–45%. These treatment pairs produced gaps of 5–20 percentage points. Cultivar resistance strengthened control when combined with fungicide treatment. A large integrated management study reported 76% disease suppression and 71% toxin reduction. Other trials showed that wheat type, season, treatment timing, and application coverage changed observed responses. Recent Brazilian results also showed that the strongest yield response did not identify the greatest toxin reduction. These findings support related, but unequal, treatment responses. Visible disease remains useful for field assessment, but cannot replace grain toxin testing. Reliable evaluation should report disease, damaged kernels, toxin concentration, and yield together. Management decisions should combine cultivar resistance, suitable disease protection, and testing of harvested grain.

Keywords: Fusarium head blight; wheat; deoxynivalenol; fungicide; treatment agreement; cultivar resistance; grain quality.

الملخص:
تتسبب لفحة السنبلة بالفيوزاريوم في خفض محصول القمح، كما تتسبب في تلوث الحبوب بالسموم الفطرية، وبشكل خاص سم الديوكسي نيفالينول (Deoxynivalenol). وتستطيع مبيدات الفطريات الحد من كلتا المشكلتين، إلا أن تأثيراتها لا تتطابق دائمًا .بحثت هذه الدراسة في مدى التوافق بين كبح المرض وتقليل السموم باستخدام البيانات والأبحاث المتاحة .وشملت المراجعة المرجعية المستهدفة أبحاثًا وتجارب حقلية، ومراجع علمية، وتحليلات تلوية (Meta-analyses) منشورة .واعتمدت المقارنات الرقمية على التأثيرات المسجلة للمعاملات مقارنة بمجموعات الشواهد (مجموعات المقارنة) الأصلية .وتُحُقِّقَ من التوافق من خلال اتجاه الاستجابة، وترتيب كفاءة المعاملات، والفروق بين النسب المئوية للانخفاض، دون إجراء تجارب حقلية جديدة أو اختبارات إحصائية مجمعة.

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أظهرت الأدلة المنشورة وجود علاقة إيجابية بين ظهور الأعراض المرضية ومستويات الديوكسي نيفالينول، مع وجود تباين كبير بين الدراسات .وسجل أحد التحليلات الرئيسية انخفاضًا في أعراض المرض بنسبة 32–52%، مقابل انخفاض في تركيز السموم بنسبة 12–45%، مما أظهر فجوة بين النتيجتين تراوحت بين 5 و20 نقطة مئوية .كما أدت المقاومة الوراثية للصنف إلى تعزيز كفاءة المكافحة عند دمجها مع المعاملة بمبيدات الفطريات؛ حيث سجلت دراسة موسعة للإدارة المتكاملة كبحًا للمرض بنسبة 76% وتقليلًا للسموم بنسبة 71.%

وأظهرت تجارب أخرى أن نوع القمح، والموسم، وتوقيت التطبيق، وتغطية رش المبيد أدت جميعها إلى تغيير الاستجابات المرصودة .كما بينت نتائج حديثة من البرازيل أن الاستجابة الأعلى للمحصول لم ترافقها أعلى نسبة انخفاض في السموم . وتدعم هذه النتائج فكرة أن استجابات المعاملات مرتبطة ببعضها لكنها غير متساوية .وبالتالي، تظل الملاحظة الظاهرية للمرض مفيدة للتقييم الحقلي، لكنها لا تغني عن إجراء الفحوصات المخبرية للسموم في الحبوب .ويجب أن يشتمل التقييم الموثوق على تسجيل معدل الإصابة بالمرض، والحبوب المتضررة، وتركيز السموم، والمحصول كمنظومة واحدة .كما ينبغي أن تعتمد قرارات المكافحة والإدارة على الجمع بين زراعة الأصناف المقاومة، وتوفير الحماية الفطرية المناسبة، وفحص السموم في الحبوب بعد الحصاد.

الكلمات المفتاحية: لفحة السنبلة بالفيوزاريوم؛ القمح؛ الديوكسي نيفالينول؛ مبيدات الفطريات؛ توافق المعاملة؛ مقاومة الصنف؛ جودة الحبوب.

Introduction

A wheat crop can show fewer diseased heads while still producing grain containing unwanted toxins. This difference matters when fungicide performance is judged mainly through visible symptoms. Farmers need disease protection, while grain buyers also need reliable evidence of grain quality. These needs overlap, but they require separate measurements.

Fusarium head blight, called FHB here, affects wheat heads and developing grain. Several Fusarium species can contribute to the disease. Deoxynivalenol, called DON here, is a major toxin associated with affected wheat. Research has therefore measured both disease symptoms and grain contamination (McMullen et al., 2012).

The question behind treatment agreement

The word suppression describes a reduction in disease compared with an untreated crop. Toxin reduction describes a decrease in measured contamination against a suitable control. Both responses can be expressed as percentages. Equal percentages, however, do not mean the measurements represent the same biological process.

An FHB score describes symptoms observed in the crop. A DON result describes a chemical concentration measured in a grain sample. The measurements occur at different times and use different sampling units. Their connection must therefore be examined rather than assumed.

Earlier research found positive associations between disease indicators and DON concentrations. The strength of these associations differed across indicators and study settings (Paul et al., 2005). Such results explain why visual assessment remains useful. They also explain why visual assessment cannot supply an exact toxin concentration.

Agreement has several meanings within this paper. Directional agreement means that treatment reduces both disease and DON. Ranking agreement means that treatments appear in similar orders for both outcomes. Magnitude agreement means that the percentage reductions are close. A treatment can meet the first condition while failing the third.

Purpose and scope

This paper examines whether published fungicide effects support similar conclusions about disease suppression and toxin reduction. It compares reported reductions, describes their differences, and considers practical reasons for unequal responses. It also examines how cultivar resistance changes the comparison.

The working expectation was that effective disease treatments would usually reduce DON. Equal reductions were not assumed. The analysis instead asked whether differences remained

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large enough to affect interpretation. This approach keeps the research question focused on paired outcomes.

The title uses mycotoxin reduction broadly, but the numerical evidence concerns DON. Other Fusarium toxins require separate measurements and separate conclusions. A decline in DON does not establish a decline in every toxin. The findings should therefore be read primarily as evidence about DON.

The paper draws on published experiments. Several sources combine results from many locations. Others describe individual field research programs. These evidence types offer different strengths, and their results remain separate throughout the paper.

The practical issue is straightforward. Disease appearance can help judge crop response, but grain testing answers a different question. Keeping both outcomes visible gives a clearer assessment of fungicide performance. It also prevents a successful disease result from becoming an unsupported grain quality claim.

Materials and methods

Literature identification and selection

A targeted literature search was completed on 25 October 2025. Searches used a scholarly index, PubMed records, publisher pages, and institutional repositories. Search terms combined wheat, Fusarium head blight, fungicide, DON, deoxynivalenol, resistance, and treatment efficacy. References within relevant papers provided additional leads.

Sources were selected for their relevance to paired disease and toxin outcomes. Priority was given to wheat field studies and quantitative reviews. Papers describing cultivar resistance, treatment timing, or application coverage supplied supporting evidence. A statistical paper clarified the distinction between association and agreement.

Fourteen references were retained for this focused synthesis. This was a targeted review rather than an exhaustive systematic review. Selection emphasized studies with comparable disease and toxin outcomes. The scope supported close examination of the treatment agreement question.

Public availability included accessible abstracts, complete articles, and institutional copies. Some publisher pages provided summaries without unrestricted full text. Numerical extraction was limited to values visible in accessible source material. Missing treatment values were left unreported Mayor .

Outcome definitions

Disease terms were retained because they describe different observations. Incidence measures affected heads, while severity describes affected tissue within heads. An index combines disease frequency and severity at crop or plot level. Damaged kernels provide a grain based indicator.

Table 1. Outcomes used when comparing disease and grain contamination

Outcome	Meaning	Main caution
FHB incidence	Proportion of heads showing disease	Does not measure within-head damage
Diseased-head severity	Affected spikelets within diseased heads	Depends on the scoring denominator
FHB index	Plot or crop level disease intensity	Definitions must match across comparisons
Damaged kernels	Visible Fusarium damage in grain	Appearance does not measure toxin directly
DON concentration	Measured toxin per mass of grain	Depends on representative grain sampling
Grain yield	Harvested grain per land area	Cannot establish toxin acceptability

Definitions follow Paul et al. (2005) and McMullen et al. (2012).

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DON was kept separate from visible disease throughout extraction. Yield was included only where it helped explain different treatment priorities. The review did not reconstruct unpublished field or laboratory measurements.

Evidence extraction and study boundaries

The extracted information included study setting, wheat type, comparison group, and reported disease and DON effects. Published percentages were retained at their reported precision. Differences calculated here used those rounded values. The underlying plot observations were not reconstructed.

Table 2. Main publicly available experimental evidence

Source	Study coverage	Use in this paper
Paul et al. (2008)	Over 100 trials; 14 US states	Paired fungicide effects
Wegulo et al. (2011)	Five experiments; 2007–2009	Cultivar and fungicide interaction
Mesterházy et al. (2011)	Hungarian research programs	Coverage and scale effects
Haidukowski et al. (2012)	20 Italian field experiments	Common and durum wheat responses
Willyerd et al. (2012)	Over 40 trials; 12 US states	Integrated management comparisons
D'Angelo et al. (2014)	Seven experiments; Ohio and Illinois	Treatment timing evidence
Barro et al. (2023)	19 Brazilian trials; 2017–2021	Disease, DON, and yield priorities

Coverage describes the source studies. Trial totals are not added because some research programs may overlap.

Measures of treatment response

Percentage reduction was calculated against the control used by each original study. The same control must apply to both outcomes within a treatment pair. The following expressions describe the comparison:

$$CFHB = 100 \times (1 - Itreated / Icontrol)$$
$$CDON = 100 \times (1 - Dtreated / Dcontrol)$$
$$G = CFHB - CDON$$

I represents the reported disease measure, and D represents DON concentration. G is the difference in percentage points. Positive G means greater disease suppression than DON reduction. Negative G means greater DON reduction. This difference describes reported effects; it is not a significance test.

No new pooled estimate was calculated. Source studies differed in controls, wheat types, treatments, and available uncertainty measures. Combining their averages would create false precision. The analysis therefore reports within-source comparisons and qualified comparisons across settings.



Photographs 1 and 2. (Left) A wheat head with bleached spikelets. (Right) Fusarium-damaged grain (left pile) and healthy grain (right pile). Source: Wegulo (2012)

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Results

Disease and toxin levels were associated

Paul et al. (2005) examined 163 studies of disease indicators and DON. Reported correlations ranged from negative values to strong positive values. Mean relationships were positive for all four indicators. Damaged kernels showed the strongest average association.

Table 3. Published mean correlations between disease indicators and DON

Indicator	Mean correlation r	Interpretation
Fusarium-damaged kernels	0.73	Strongest average relationship
FHB index	0.62	Moderate positive relationship
Diseased-head severity	0.53	Lower average relationship
FHB incidence	0.52	Lower average relationship

Source: Paul et al. (2005). Values describe association, not equal treatment effects.

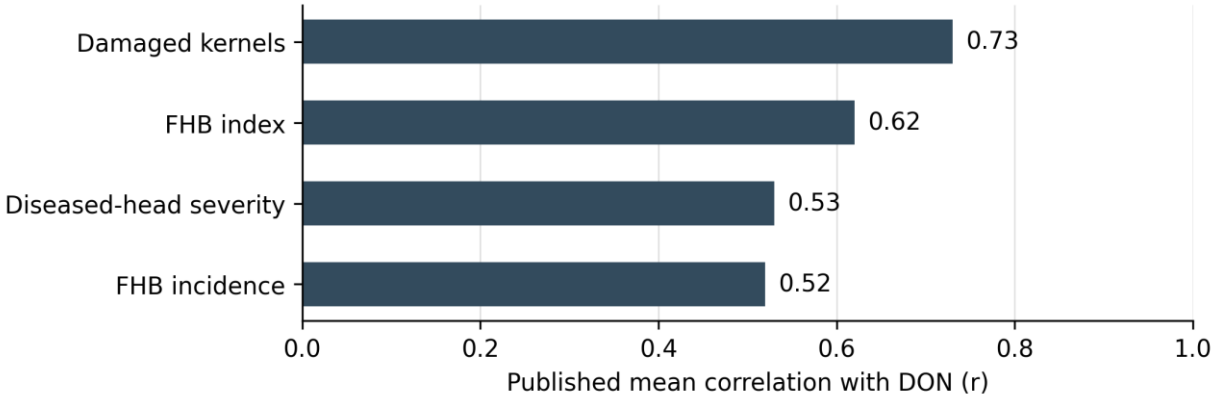


Figure 1 Mean relationships between disease indicators and DON. Mean correlations from 163 studies are shown. These values measure association, rather than equality of treatment effects. Source: Paul et al. (2005). The chart was drawn from published summary values.

These results support disease assessment as a useful source of information. They do not show that one outcome can replace another. A correlation can remain positive when DON reductions are consistently smaller. It can also remain positive when treatment rankings differ near the top. The strongest indicator still leaves important uncertainty for individual grain samples. A field observer sees symptoms across heads. The laboratory receives a smaller grain sample. Differences in scale can affect the apparent relationship even when both measurements are correct.

An early fungicide review showed unequal reductions

The tebuconazole review reported 40.3% disease suppression and 21.6% DON reduction (Paul et al., 2007). Their difference was 18.7 percentage points. Both outcomes improved, but the toxin response was smaller. Figure 2 displays this simple example of directional agreement with unequal magnitude.

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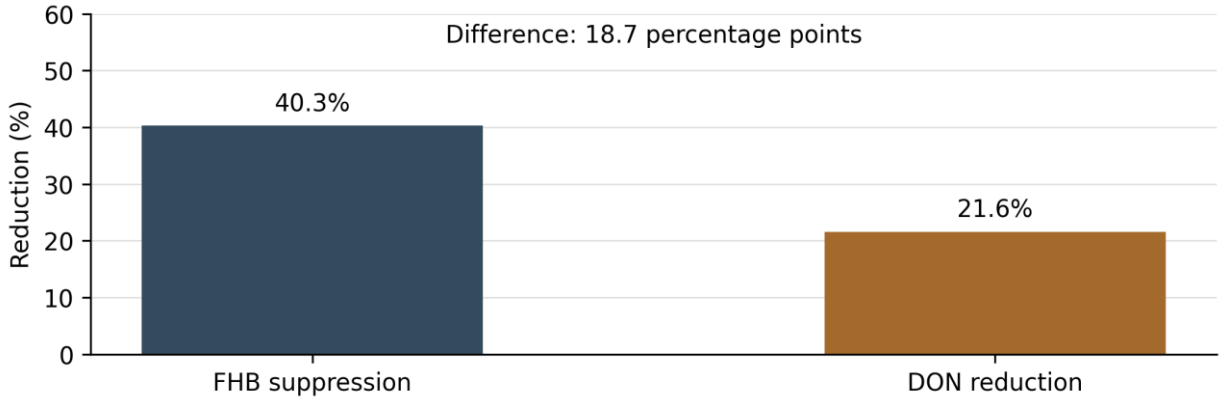


Figure 2: Unequal disease and DON responses to tebuconazole. Published mean reductions were 40.3% for disease and 21.6% for DON. Their calculated difference is 18.7 percentage points. Source: Paul et al. (2007).

This example matters because a positive result can hide a sizeable response gap. Calling the treatment effective does not explain which outcome improved most. The reader needs both percentages, the comparison group, and the measured grain concentration.

A lower percentage reduction also has no fixed meaning without the starting concentration. The same proportional improvement can produce very different final grain results. Reported control efficacy should therefore accompany absolute DON measurements whenever those measurements are available.

Paired triazole results showed clear gaps

Paul et al. (2008) compared five fungicide treatments across a broad US research network. Every reported mean pair showed disease and DON reductions. Disease suppression exceeded DON reduction in all five pairs. Table 4 preserves the original treatment comparisons.

Table 4. Disease suppression and DON reduction in the triazole meta analysis. Source: Paul et al. (2008).

Treatment	FHB reduction %	DON reduction %	Gap in points
Prothioconazole + tebuconazole	52	42	10
Metconazole	50	45	5
Prothioconazole	48	43	5
Tebuconazole	40	23	17
Propiconazole	32	12	20

Gap equals FHB reduction minus DON reduction. Values are rounded published means.

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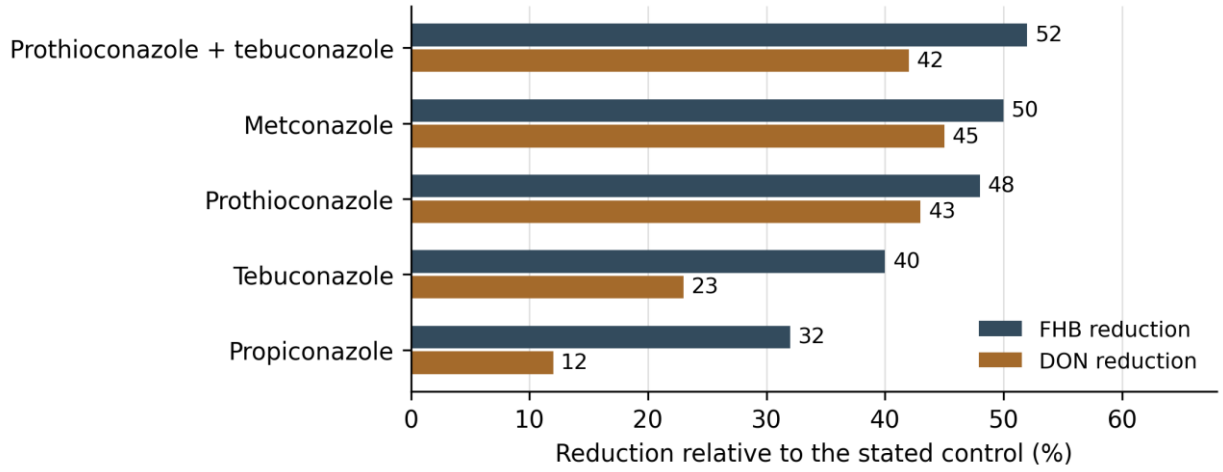


Figure 3: Paired reductions across five triazole treatments. Disease and DON reductions share the original untreated comparison. Values are rounded model summaries, rather than individual field measurements. Source: Paul et al. (2008).

The treatment with the greatest disease suppression did not have the greatest DON reduction. Metconazole had the highest DON point estimate. The mixture had the highest disease point estimate. These rankings describe reported means and do not establish significant differences between closely ranked treatments.

The calculated gaps ranged from five to twenty percentage points. These differences show why equal direction should not be described as equal control. They also show that the size of disagreement depends on treatment. A single correction factor would not describe all five pairs.

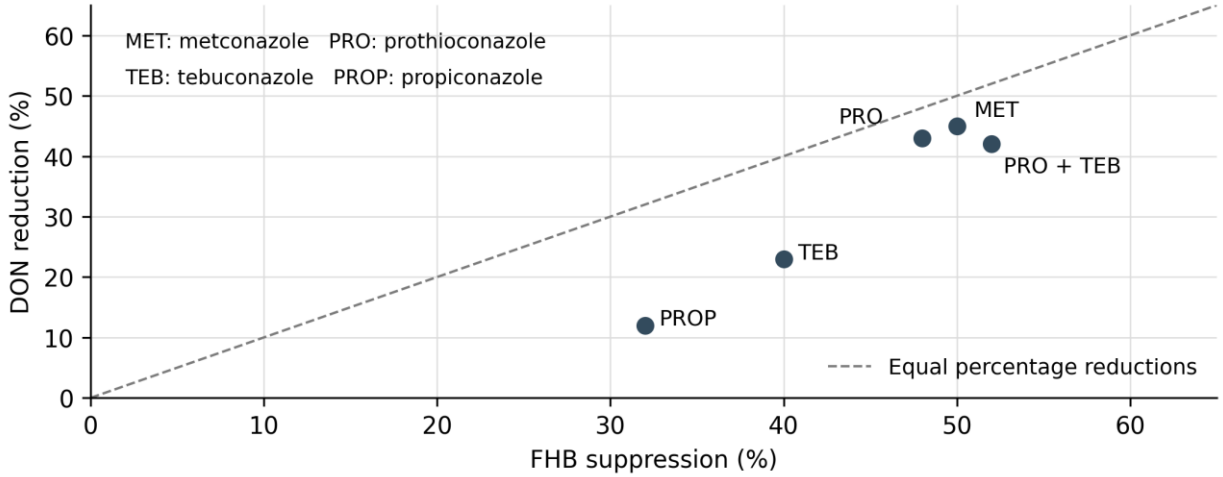


Figure 4 :Disease and DON effects against an equality line. The dashed line marks equal percentage reductions. All five summary points fall below that line. Source data: Paul et al. (2008).

Figure 4 places the five means against an equality line. Points below that line indicate smaller DON reductions. The graph displays treatment summaries rather than individual trial observations. Its pattern cannot provide a probability of agreement for a future field.

No confidence limits were calculated for the gaps. Their uncertainty depends on the relationship between the two effect estimates. Separate standard errors would not fully describe that relationship. Rounded summary values cannot supply the missing covariance.

The comparison supports a practical reading of treatment evidence. Disease suppression gives one part of the result. DON reduction gives another part. Neither percentage should be substituted for the other when grain contamination is the main concern.

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Photograph 3. A wheat field affected by Fusarium head blight in Nebraska, USA, in 2008. Source: Wegulo (2012)

Cultivar resistance changed both outcomes

Willyerd et al. (2012) combined cultivar resistance and fungicide treatment across more than forty trials. Their reference was untreated susceptible wheat. The best combined category reduced disease by 76% and DON by 71%. These results describe an integrated management contrast.

Table 5. Integrated management effects against untreated susceptible wheat. Source: Willyerd et al. (2012).

Management category	FHB reduction %	DON reduction %	Gap in points
Moderately resistant and treated	76	71	5
Moderately susceptible and treated	71	58	13
Moderately resistant and untreated	54	51	3
Susceptible and treated	53	39	14
Moderately susceptible and untreated	43	30	13

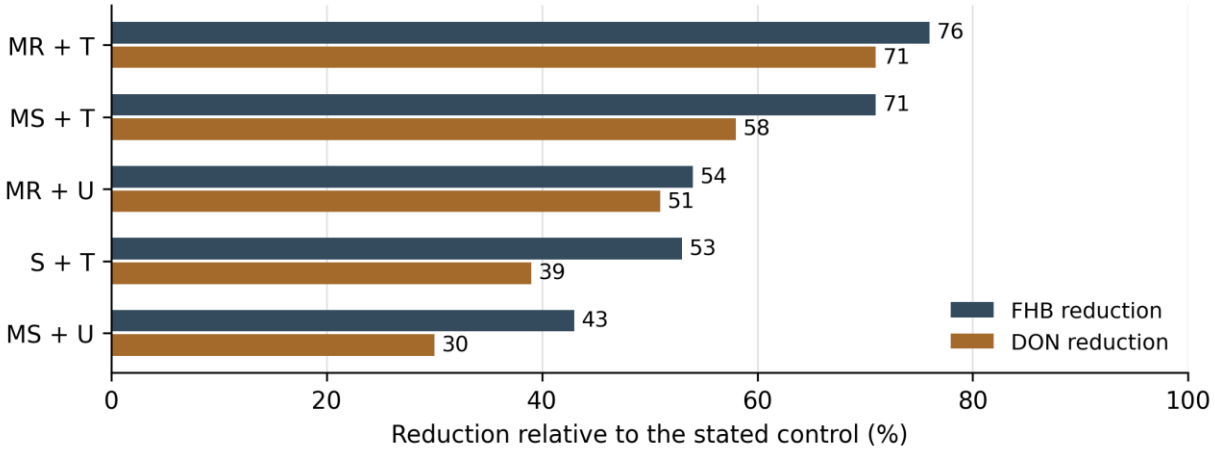


Figure 5: Combined cultivar and fungicide management effects. All reductions use untreated susceptible wheat as the reference. S, MS, and MR indicate susceptible, moderately susceptible, and moderately resistant categories. T means treated; U means untreated. Source: Willyerd et al. (2012).

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The two outcome rankings matched across these five categories. Their reduction magnitudes still differed. This combination shows that ranking agreement can be strong despite unequal percentage responses. It also shows the value of reporting more than one meaning of agreement.
The untreated resistant category cannot be interpreted as a fungicide response. Its benefit reflects a cultivar comparison. The treated resistant category includes both cultivar and chemical effects. Keeping these contrasts separate prevents an inflated claim about fungicide performance alone.
A further distinction concerns the control group. A treated resistant cultivar should be compared with its untreated counterpart for fungicide-only efficacy. Comparing it with untreated susceptible wheat answers the broader management question. Both comparisons can be useful, but they answer different questions.
The three-point gap in untreated resistant wheat was smaller than several treated-category gaps. This observation does not establish that withholding fungicide improves agreement. The categories also differ in resistance and baseline response. The published evidence supports integrated control rather than a treatment withdrawal rule.
The combined category achieved the largest reductions in both outcomes. Its smaller response gap adds context, but does not prove grain acceptability. Final DON concentration remains necessary for that judgment. Relative improvement and final grain quality must remain distinct.

Field experiments explained variation among studies

Wegulo et al. (2011) conducted five experiments between 2007 and 2009. They compared winter wheat cultivars with different resistance levels under fungicide treatment. Disease and DON responses depended on cultivar resistance. Moderately resistant cultivars showed greater percentage fungicide efficacy than susceptible cultivars.
These experiments support the integrated pattern found in the larger research network. They also caution against treating every cultivar as an equivalent test background. A product result from susceptible wheat cannot automatically predict the result from resistant wheat. The host remains part of the treatment setting.
Haidukowski et al. (2012) reported twenty Italian field experiments across five growing seasons. Prothioconazole-based treatments reduced disease by 39–93%. Reported DON reductions ranged from 40–91%. The research included common wheat and durum wheat.

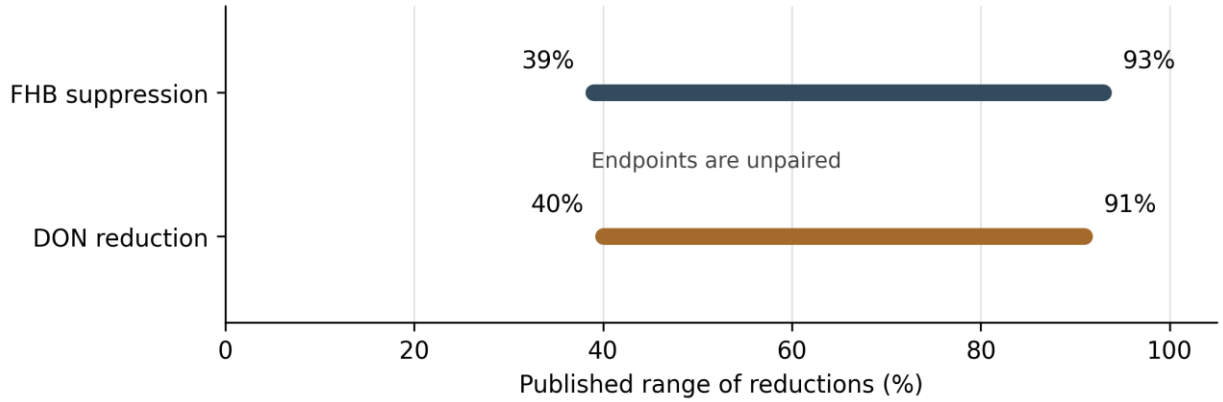


Figure 6 : Reported response ranges from Italian experiments. Ranges summarize prothioconazole-based treatment responses across twenty experiments. Range endpoints are not matched treatment pairs or confidence intervals. Source: Haidukowski et al. (2012).

These wide ranges show substantial variation in treatment performance. Their endpoints must not be paired as individual observations. The lowest disease reduction may come from a different comparison than the lowest DON reduction. Calculating agreement from the two range endpoints would therefore be misleading.

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The Italian study reported stronger DON reduction and yield responses in common wheat than durum wheat. Wheat type therefore matters when interpreting external evidence. A wide geographical research base improves understanding, but does not remove differences between crop classes.

Mesterházy et al. (2011) examined treatment performance across Hungarian research settings. Their work considered cultivar resistance, fungicide performance, and application coverage. Small plots and farm settings helped test whether observed benefits transferred across scales. Their findings connected application quality with disease and DON responses.

Coverage is relevant because wheat heads present several exposed surfaces. A treatment can reach some parts better than others. The resulting crop response may therefore be uneven. A field average can hide that variation, especially when grain is later combined.

The same research reported situations where susceptible cultivars remained above the relevant historical DON threshold. Visible disease had nevertheless declined. This is direct evidence that symptom improvement need not establish an acceptable toxin result. Historical thresholds are not treated here as current legal limits.

Timing evidence required its own interpretation

Seven experiments evaluated treatment timing in soft red winter wheat (D'Angelo et al., 2014). A later analysis examined nineteen years of timing trials (Paul et al., 2018). These studies show that timing can change disease and DON responses. Their results do not support one universal response percentage.

Timing evidence should be read within its original wheat class and treatment comparison. A response observed under one season may not transfer unchanged. This paper uses timing as an explanation for variation. It does not convert published experiments into a local spray prescription.

Brazilian trials separated disease toxin and yield priorities

Barro et al. (2023) analyzed nineteen cooperative trials from southern Brazil. Their data covered five seasons between 2017 and 2021. Several treatments reduced both disease and DON. Selected paired estimates are presented below.

Table 6. Selected paired effects from Brazilian wheat trials. Source: Barro et al. (2021).

Treatment	FHB reduction %	DON reduction %	Gap in points
Metconazole	62.8	65.1	−2.3
Pyraclostrobin + metconazole	56.1	58.3	−2.2
Tebuconazole + trifloxystrobin	41.5	50.0	−8.5

The negative gaps show that DON reduction can exceed disease suppression. This differs from the direction of gaps in Table 4. The difference is descriptive. Separate regions, programs, and comparisons prevent attribution to any single cause.

Yield ranking also differed from DON ranking. The largest yield gain accompanied a three-ingredient treatment. That treatment had the smallest DON reduction among the six reported options. Figure 7 displays both outcomes without combining their different units.

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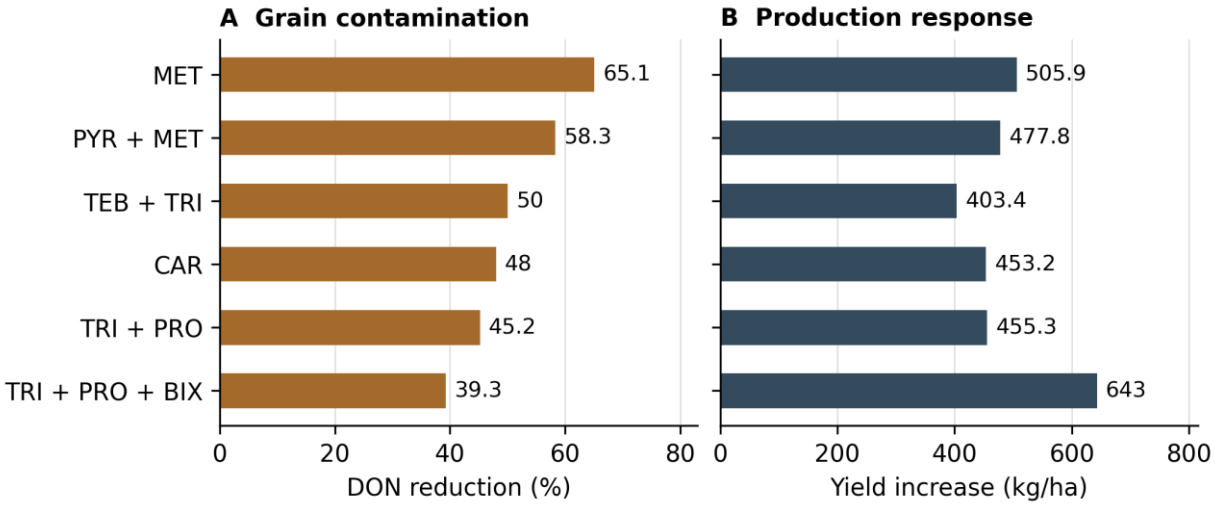


Figure 7: Different DON and yield priorities in Brazilian trials. Panels use separate units and retain the same treatment order. Values are model summaries from nineteen trials. MET, PYR, TEB, TRI, PRO, BIX, and CAR mean metconazole, pyraclostrobin, tebuconazole, trifloxystrobin, prothioconazole, bixafen, and carbendazim. Source: Barro et al. (2023).

A recent integrated management study showed strong reductions

A Kansas study covered four years and two locations each year. It compared resistance levels with two fungicide products. The strongest combined category reduced FHB by 98.7% and DON by 93% . The comparison used untreated susceptible wheat.

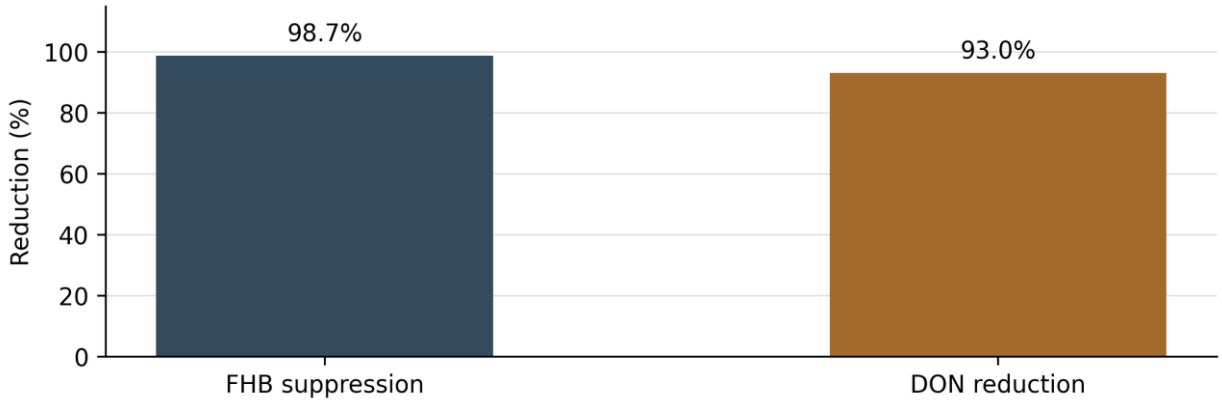


Figure 8 :A recent integrated management comparison in Kansas.
The reported best combined category reduced disease by 98.7% and DON by 93%. The reference was untreated susceptible wheat

The resulting difference was 5.7 percentage points. This result supports the value of combining resistance and treatment. It does not establish that every field will achieve similar control. Its magnitude should remain attached to the original study conditions.

The Kansas result was stronger than several earlier summary estimates. This comparison cannot establish historical improvement in product efficacy. Control groups, cultivars, disease pressure, and research settings differed. The newer study supplies another example, rather than a direct test against earlier studies.

Taken together, these examples support related responses with variable magnitude. Some comparisons showed larger disease reductions. Others showed larger DON reductions. The evidence does not support a fixed relationship that converts one treatment outcome into the other.

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Discussion

Why symptom suppression can differ from toxin reduction

Visible symptoms and grain contamination describe different parts of the disease outcome. Symptoms record plant damage observed during crop development. DON measurement records contamination in harvested grain. The time between these observations allows their relationship to change.

Wegulo (2012) reviewed several influences on DON accumulation in cereals. These included weather, crop development, host resistance, and disease management. The review also described grain contamination that was poorly represented by visible kernel damage. Such evidence explains why appearance alone remains an incomplete guide.

A fungicide result therefore contains more than a change in head appearance. The measured grain result also reflects the crop background and harvest sample. Treatment can influence one part of this chain more strongly than another. A shared disease origin does not require equal numerical responses.

The denominator further affects proportional reductions. A control with severe disease can produce a large percentage reduction after treatment. A different starting DON concentration can produce another percentage. Comparing the resulting percentages describes response balance, but does not make the original measurements identical.

Percentages can also hide residual risk. A large DON reduction may leave a considerable final concentration. A smaller reduction may accompany a low final concentration. The percentage describes improvement, while the final measurement describes the grain actually available.

Association agreement and interchangeability

Bland and Altman (1986) explained why correlation alone cannot establish agreement between measurements. Their statistical principle helps interpret this agricultural question. FHB and DON are different outcomes, however, rather than competing instruments measuring one quantity. Their raw values should not enter a conventional agreement analysis.

Percentage treatment effects provide a shared descriptive scale. Even then, equal percentages indicate equal proportional change rather than biological interchangeability. An equality line is therefore a visual reference. It is not proof that disease scoring can replace chemical measurement.

The paired triazole estimates demonstrate this distinction. Every treatment improved both outcomes, yet their point estimates differed. The highest-ranked treatment also depended on the outcome chosen. Agreement must therefore be stated in terms of direction, ranking, or magnitude.

A formal claim of close agreement would need a justified tolerance. That tolerance should reflect a practical decision before examining the results. No tolerance cutoff was specified for this review. Differences are reported in percentage points, with their practical context kept visible.

Future paired analyses could examine the average gap and its uncertainty within studies. They would require matched treatment effects and their dependence structure. Several treatment comparisons may share one untreated group. Treating those comparisons as independent would exaggerate the amount of evidence.

What the findings mean for treatment evaluation

The evidence supports evaluating crop protection through more than one outcome. Disease scoring shows whether symptoms declined. Grain testing shows whether DON declined. Yield shows the production response. These observations should appear together when a study makes broad claims about treatment value.

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This distinction changes how treatments are compared. A product selected for disease appearance may not lead the DON ranking. A product selected for yield may not provide the greatest DON reduction. Research reports should state which outcome drives their conclusion. The Brazilian results provide a useful example of different priorities. Their yield and DON comparisons do not lead to identical rankings. The practical lesson concerns measurement and reporting. It does not justify transferring that treatment ranking to another country without local evidence.

Cultivar resistance deserves similar care. Integrated categories often show stronger overall control than fungicide treatment alone. Their value should be reported as a combined management effect. Clear comparison groups protect readers from attributing the entire benefit to one component.

For harvested grain, representative sampling remains essential. A precise laboratory result cannot correct an unrepresentative sample. Disease can vary across a field and contamination can vary across a grain lot. The sampling plan should therefore match the lot being evaluated.

A disease score can guide attention toward higher-risk fields. It cannot confirm the toxin concentration of a marketed lot. This distinction supports grain testing when contamination affects acceptance or use. Applicable limits should be checked for the intended market and grain product.

Priorities for stronger published evidence

Future studies should preserve paired disease and DON results for each treatment comparison. They should identify the untreated group and cultivar clearly. Public tables should include absolute means, relative effects, replication information, and uncertainty estimates. This would make later agreement analysis more reliable.

Shared controls should be identified in public datasets. Site and season identifiers should accompany treatment records. These fields allow analysts to retain the study structure. They also reduce the risk of counting the same trial more than once.

Several useful questions remain open. Researchers could examine whether response gaps differ between wheat classes. They could also assess whether stronger resistance makes those gaps more stable. Such questions require sufficient paired observations rather than comparisons between isolated published averages.

Other toxins need direct attention when the research question includes them. DON results cannot supply missing nivalenol or zearalenone measurements. Each toxin should retain its own outcome definition. A broader mycotoxin conclusion requires broader analytical evidence.

Figure reporting can also improve transparency. Charts should identify whether values represent observations, model estimates, or calculated summaries. Confidence intervals should appear when available. Captions should identify the source and control group without requiring readers to guess.

Limitations

This study used a focused selection of relevant literature. It did not attempt a complete systematic search or a new meta analysis. The selected evidence emphasizes US research, with useful Italian, Hungarian, and Brazilian comparisons. Other production regions may show different response patterns.

Several sources are published syntheses rather than independent new trial datasets. Their underlying experiments may overlap. Trial counts were therefore not summed. The paper also avoided calculating a pooled average across these sources.

The numerical comparisons rely on rounded published means. Most comparisons lacked complete paired uncertainty information in the accessible summaries. Calculated gaps should

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therefore be read as descriptive differences. Their size alone does not establish statistical significance.

Study averages also conceal variation among fields. A small average gap could occur alongside large positive and negative gaps. Reporting only the average would miss this pattern. Distributional information is therefore needed before claiming reliable agreement across farming conditions.

Some sources provided publicly accessible abstracts rather than complete underlying datasets. Results absent from those summaries were not estimated. The Italian ranges were not converted into matched treatment pairs. This preserves a necessary boundary between available evidence and unsupported reconstruction.

The figures show reported point estimates and clearly identified ranges. The equality plot uses aggregate treatment summaries. These results describe study averages rather than individual farms or grain lots.

Finally, most numerical evidence concerns DON. The conclusions should not be extended to every Fusarium mycotoxin. Disease control remains relevant across this wider problem. Direct measurements are still needed for each toxin of interest.

Conclusion

FHB suppression and DON reduction usually move in the same direction under effective wheat disease management. Their percentage responses can still differ substantially. Published examples include unequal treatment rankings and gaps reaching twenty percentage points. Other comparisons show greater DON reduction than disease suppression.

Cultivar resistance improves the overall management outcome when combined with suitable fungicide treatment. The strongest combined categories can reduce both disease and DON considerably. These benefits remain specific to their original controls and settings. They should not be described as fungicide-only effects.

Visible disease provides useful field information, but it cannot replace toxin testing of harvested grain. Reliable evaluation should report symptoms, damaged kernels, DON concentration, and yield together. Clear controls and paired reporting are necessary for meaningful agreement claims.

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