BARLEY SCAB: FORECASTING TO MANAGEMENT

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Outline

- DON prediction model
- Contribution of secondary tillers to final DON level in harvest grain
Development of Weather-Based Predictive Models for Fusarium Head Blight and Deoxynivalenol Accumulation for Spring Malting Barley

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SM Neate, Leslie Research Center, Australia (previously NDSU)
SH Halley, NDSU
LE Osborne, Pioneer HiBred International (previously SDSU)
CR Hollingsworth, USDA-APHIS-CHPST (previously UMN-Crookston)

Fusarium Head Blight (FHB)

- Caused by *Gibberella zeae* (Schwein) petch (anamorph: *Fusarium graminearum* Schwabe)

- Economic losses due to
  - Blighting of florets (reduction in grain number)
  - Disruption of grain fill (shriveled kernel - light test weight)
  - Quality compromised (mycotoxin contamination – DON)

Impact on barley

- Low tolerance for DON in malting barley
- Gushing in absence of agitation
- Severe discount of crop rejection if the DON level exceeds 0.5 mg/kg

FHB management in barley

- FHB resistance is not adequate
- Inoculum management through crop or residue management
- Fungicide application – timing is critical
- Development of risk advisory system help to make informed management decision

Objectives

- develop a FHB infection model based on temperature and wetness duration, and
- develop risk models that were predictive of DON levels greater than 0.5 mg/kg.
Materials & methods

- RCBD – 4 reps
- Regionally adapted-malting barley in multiple locations
- 2005-09: to develop potential predictive models
- 2010 (ND, SD): validation.
- At least ‘Conlon’ (2-row), ‘Robust’ and ‘Tradition’ (6-row) common
- Plot size: 1.5m x 4.6m
- Natural infection

Materials & methods

• Disease rating at 18-21 dai heading (Z85) – 25 heads per plot

• DON analyses on harvested grain

• Weather data temperature, RH and precipitation (incidence and rate) – used for calculating other variables

• 9 days preceding and including heading day

• Binary response variable _economic DON (eDON) – economically significant DON – 0.5 mg/kg

Infection model @ controlled envt.

- Non-linear relationship between temp ($t$) and duration of continuous wetness ($w$) expressed using modified Weibull function given by Duithe (1997)

$$Y = f(w,t) = A\left(1 - \exp\left\{ -[B(w - C)]^D\right\}\right)$$

- Where $B$ varies with temperature according to

$$B = f(t) = E\left[(H + 1)/H\right]H^{1/(H+1)}\{\exp[(t - F)G/(H + 1)]\}/\{1 + \exp[(t - F)G]\}.$$ 

- $A =$ upper limit of the response, $B =$ intrinsic rate of increase in repose with respect to $w$, $C =$ lag period of $w$ before response begins, $D =$ periods of wetness in which response decelerates, $E =$ scale of response to $t$, $F =$ proportional to optimal $t$, $G =$ intrinsic rate of change in the response with respect to $t$, $H =$ asymmetry in the response to $t.$

• FHB infection in wheat data (Anderson, 1948) used for estimation of parameters

• Response variable: proportion of symptomatic wheat spikelets at a given $t$ and $w$

• To reduce over parameterization, $A$, $C$, and $F$ were fixed to 1, 12 and 25, respectively

• Best-fit parameter estimates for $D$, $E$, $G$, and $H$ were obtained using Marquardt iterative method of the NLIN procedure in SAS
Parameter estimates and associated statistics for the Weibull model using disease incidence data from a control envt. Study with wheat.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Estimate</th>
<th>Asymptotic Standard Error</th>
<th>95% confidence interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>D</td>
<td>2.6475</td>
<td>0.0903</td>
<td>0.8859 - 1.2628</td>
</tr>
<tr>
<td>E</td>
<td>0.0252</td>
<td>0.0015</td>
<td>0.0222 - 0.0282</td>
</tr>
<tr>
<td>G</td>
<td>0.4804</td>
<td>0.4354</td>
<td>1.7393 - 3.5558</td>
</tr>
<tr>
<td>H</td>
<td>1.0744</td>
<td>0.0436</td>
<td>0.3895 - 0.5713</td>
</tr>
</tbody>
</table>

Parameter estimates were obtained by using the Marquardt procedure defined in PROC NLIN in SAS.

The response variable was considered as proportion of inoculated wheat spikelets blighted at different temperatures and exposure period to wetness provided by Andersen (1948).

The parameters A, C, and F were fixed at 1, 12 h and 250C as explained previously.
Predicted response surface generated by the Weibull function using disease incidence data from a controlled environment study with wheat. The parameters $A$, $C$, $D$, $E$, $F$, $G$ and $H$ were 1.0, 12.0, 2.6475, 0.0252, 25.0, 0.4804, and 1.0744, respectively.

Extension of infection model to field

- Several input variables were developed to estimate $t$ and $w$
  - Temperature: average hourly temperature (AvgT), average daily min. temp (AvgMinT), avg. daily max temp (AvgMaxT)
  - Wetness duration: no. of hours with RH ≥ 90% (RH90), longest uninterrupted duration of hours with RH ≥ 90% (drRH90), and weighted duration of hours with RH ≥ 90% (wRH90)

\[ w_{RH90} = \frac{\sum x_i}{\sum W_i} \left( 1 + \frac{W_i}{\sum W_i} \right) \]

\[ W_i = \begin{cases} x_i - 8 & \text{if } x_i > 8; \\ 0 & \text{otherwise} \end{cases} \]

$x_i$ = instance of uninterrupted wetness duration (h) when RH ≥ 90%

$i$ = indicator to represent such uninterrupted durations in the 10-day interval

Extension of infection model to field

• For each event, $Y$ was calculated using eqn 1 replacing $t$ and $w$ with different variables

$$Y = f(w,t) = A\left(1-\exp\left\{-[B(w-C)]^D\right\}\right)$$

• Total of 9 variables were calculated (weibull variables)

• Parameters $A$, $C$, and $F$ fixed at 1, 0 and 25 and estimates from the fitting of the model to Anderson’s data were used for $D$, $E$, $G$, and $H$

Extension of infection model to field

<table>
<thead>
<tr>
<th>Variable name</th>
<th>$t$</th>
<th>$w$</th>
<th>Disease Metrics</th>
<th>Incidence</th>
<th>Field severity</th>
<th>DON</th>
<th>eDON</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wb₁</td>
<td>AvgT</td>
<td>RH90</td>
<td></td>
<td>0.55**</td>
<td>0.37***</td>
<td>0.40***</td>
<td>0.62***</td>
</tr>
<tr>
<td>Wb₂</td>
<td>AvgT</td>
<td>drRH90</td>
<td></td>
<td>0.44***</td>
<td>0.37***</td>
<td>0.24***</td>
<td>0.59***</td>
</tr>
<tr>
<td>Wb₃</td>
<td>AvgT</td>
<td>wRH90</td>
<td></td>
<td>0.57***</td>
<td>0.42***</td>
<td>0.39***</td>
<td>0.60***</td>
</tr>
<tr>
<td>Wb₄</td>
<td>AvgMinT</td>
<td>RH90</td>
<td></td>
<td>0.45**</td>
<td>0.27**</td>
<td>0.39***</td>
<td>0.58***</td>
</tr>
<tr>
<td>Wb₅</td>
<td>AvgMinT</td>
<td>drRH90</td>
<td></td>
<td>0.49***</td>
<td>0.43**</td>
<td>0.29***</td>
<td>0.63***</td>
</tr>
<tr>
<td>Wb₆</td>
<td>AvgMinT</td>
<td>wRH90</td>
<td></td>
<td>0.47***</td>
<td>0.30**</td>
<td>0.40***</td>
<td>0.60***</td>
</tr>
<tr>
<td>Wb₇</td>
<td>AvgMaxT</td>
<td>RH90</td>
<td></td>
<td>0.36**</td>
<td>0.35**</td>
<td>0.22**</td>
<td>0.40***</td>
</tr>
<tr>
<td>Wb₈</td>
<td>AvgMaxT</td>
<td>drRH90</td>
<td></td>
<td>0.55***</td>
<td>0.71***</td>
<td>0.14*</td>
<td>0.47***</td>
</tr>
<tr>
<td>Wb₉</td>
<td>AvgMaxT</td>
<td>wRH90</td>
<td></td>
<td>0.30***</td>
<td>0.29***</td>
<td>0.20**</td>
<td>0.35***</td>
</tr>
</tbody>
</table>

Pearson correlation coefficient between variables obtained from Weibull function and the disease metrics

$z$ ***: Significantly different from zero at $P < 0.001$ level; **: Significantly different from zero at $P < 0.05$ level; *: Significantly different from zero at $P < 0.1$ level.

Model validation

• Accuracy of logistic regression using a validation data set of 29 events collected from 10 research fields from SD and ND in 2010

• Independent of events that were used to develop regression models

• An event was observed as +ve eDON when eDON was ≥ 0.5 mg/kg and predicted as +ve eDON when the probability of being +ve eDON was ≥ $p^*$

• Prediction accuracies (total accuracy, sensitivity and specificity) – comparing the observed and predicted responses

**Logistic regression models for eDON**

<table>
<thead>
<tr>
<th>#</th>
<th>Model equation ((\beta_0 + \beta_1 \times X))</th>
<th>AUROC</th>
<th>(p^*)</th>
<th>Predictor variable value at (p^*)</th>
<th>Training Data (n=150)</th>
<th>Validation Data (n=29)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>TP(^x)</td>
<td>TN(^x)</td>
</tr>
<tr>
<td>1</td>
<td>(-3.34 + 5.39 \times Wb_1)</td>
<td>0.89*</td>
<td>0.23</td>
<td>0.40</td>
<td>76</td>
<td>85</td>
</tr>
<tr>
<td>2</td>
<td>(-3.20 + 134.34 \times Wb_2)</td>
<td>0.88*</td>
<td>0.33</td>
<td>0.02</td>
<td>79</td>
<td>94</td>
</tr>
<tr>
<td>3</td>
<td>(-3.85 + 5.16 \times Wb_3)</td>
<td>0.88*</td>
<td>0.28</td>
<td>0.56</td>
<td>82</td>
<td>84</td>
</tr>
<tr>
<td>4</td>
<td>(-2.34 + 37.96 \times Wb_4)</td>
<td>0.89*</td>
<td>0.13</td>
<td>0.01</td>
<td>91</td>
<td>75</td>
</tr>
<tr>
<td>5</td>
<td>(-2.91 + 2410.36 \times Wb_5)</td>
<td>0.87*</td>
<td>0.34</td>
<td>0.00</td>
<td>74</td>
<td>92</td>
</tr>
<tr>
<td>6</td>
<td>(-2.48 + 26.90 \times Wb_6)</td>
<td>0.88*</td>
<td>0.16</td>
<td>0.03</td>
<td>85</td>
<td>79</td>
</tr>
<tr>
<td>7</td>
<td>(-3.91 + 3.86 \times Wb_7)</td>
<td>0.80*</td>
<td>0.23</td>
<td>0.70</td>
<td>82</td>
<td>67</td>
</tr>
<tr>
<td>8</td>
<td>(-2.08 + 14.76 \times Wb_8)</td>
<td>0.72*</td>
<td>0.46</td>
<td>0.13</td>
<td>41</td>
<td>96</td>
</tr>
<tr>
<td>9</td>
<td>(-3.99 + 3.58 \times Wb_9)</td>
<td>0.79*</td>
<td>0.37</td>
<td>0.97</td>
<td>68</td>
<td>81</td>
</tr>
</tbody>
</table>

\(w\) Model equation was expressed in terms of \(logit(p)\), where \(logit(p) = log(p/(1-p))\). That is, right side of the model equation \(logit(p) = \beta_0 + \beta_1 X\) was given.

\(x\) AUROC - area under the ROC curve; \(p^*\) - The cut-off probability to classify an event as positive eDON event based on maximizing Youden’s index; TPP - Sensitivity; TNP - Specificity.

\(y\) The value of the corresponding predictor obtained from \(p^*\) was obtained from Youden’s index, and, estimates for \(\beta_0\) and \(\beta_1\) were given in the model equation.

\(z\) \(-\) Significantly greater than 0.5 at \(P<0.001\) level.

Optimal decision threshold ($p_T$)

- Models 3, 4 & 6 (higher sensitivities) used for calculating $p_T$ for a given level of $Prev$ (a priori probability that DON conc. will be greater than the threshold value of 0.5 mg/kg

Relationship between optimal decision threshold ($p_T$) and disease prevalence ($Prev$) for the selected models 3, 4 and 6. At each $Prev$, $p_T$ was obtained by minimizing the total average cost associated with misclassified events.
Average costs per hectare associated with no recommendation of fungicide spray, recommendation of fungicide spray at all times and the models 3, 4 and 6. The average cost for fungicide spray per hectare is $50. Costs are expressed in terms of U.S. dollar per hectare.
• Model 3: 18 False positive (training); 3 (validation)
• 50% from Conlon (2-row)
• False negative: 6 (training); 3 (validation)
• 2 of 6 intense rainfall or humidity >90% within 3 days after heading
• Remaining : DON just slightly above the threshold or were from 6-row cultivars
• Further validation – representing wide weather conditions
• Cultivar resistance inclusion required – currently underway
• Model may fail if weather become highly conducive beyond model’s period
The NDSU Small Grains Disease Forecasting Models assist producers in estimating the possibility of disease in their crops and give recommendations as to possible preventative applications and times for these applications. This is done in conjunction with NDAWN weather station locations within North Dakota and sections of western Minnesota and eastern Montana.

The forecasting models will return in 2012.

August 15, 2011

Attention: This forecasting service has ended for 2011. Now that we are approaching on receiving the final product of all our hard work done throughout the season, I wish you all the best for a healthy bumper crop. Good bye until the year 2012. For an update on 2011 small grain diseases in North Dakota, please read weekly past reports.
CONTRIBUTION OF SECONDARY TILLERS TO TOTAL DEOXYNIVALENOL CONCENTRATION IN HARVEST GRAIN
Background

- Higher number of tillers is desirable as it has positive impact on final grain yield
- Lateral tillers have delayed physiological development (Klepper et al., 1993)
- Late infection of wheat and barley results in low disease development but high DON concentration
- Delayed maturity of sec. tillers might be analog to the late infection
Hypothesis

• Secondary tillers tend to have higher DON concentration compared to that of main heads
**Methods**

**Experiment**

- Split-split plot design
- SDSU Agri. Experiment Station, Brookings, SD
- 5 reps
Methods
Plant materials

- Barley
  - ‘Quest’ (MR)
  - Robust’ (MS)

- Hard red spring wheat (HRSW)
  - SD3851 (cv ‘Brick’ MR, possesses $Fhb1$ QTL)
  - SD3854 (MS, lacks $Fhb1$ QTL)

- Hard red winter wheat (HRWW)
  - WesleyBC6 (MR, possesses $Fhb1$ QTL)
  - WesleyBC70 (MS, lacks $Fhb1$ QTL)
Methods
Inoculation

• 10 different isolates of *F. graminearum*
• 80,000 spores per ml; 200 ml per plot
• Backpack sprayer powered with CO$_2$
• Misting turned on 10 min per hour (5 pm – 7 am) for 14 days
• Inoculation at Feekes 10.5 and 11.2
Methods
Disease assessment & harvesting

- 25 main heads and 25 secondary tillers tagged (different color) in separate plots
- FHB incidence and severity assessed on tagged heads 18-21 DAI
- Tagged heads hand harvested and threshed
- Plots mechanically harvested at maturity
Tagged tillers

Tagged main spikes

Misting system
Methods

FDK & mycotoxins

- FDK assessment on head samples by counting scabby kernel in 100 random seeds (x 3)
- Mycotoxin analyses in same samples - @ NDSU
Methods
Barley H/L Ratio

- Wind speed 30 mph
- Heaviest (4) to lightest (1)
- H/L ratio = \( \frac{3+4}{1+2} \)
Results

Barley heads – H/L ratio & severity

FHB Severity, DON (ppm)

H/L Ratio

F10.5  F11.2  F10.5  F11.2

Quest  Robust
Results
Barley grains – H/L ratio & DON

![Graph showing H/L ratio and DON for different barley grains: Quest and Robust. The graph compares the H/L ratio and DON levels for F10.5 and F11.2 varieties.]

- H/L Ratio
- DON (ppm)

- F10.5
- F11.2
- Quest
- Robust
Results

SW heads – Severity, FDK & DON

![Graph showing Severity, FDK, and DON levels for different samples: F10.5, F11.2, Brick, and SD3854. The graph includes error bars for each sample.](image-url)
Results

WW heads – Severity, FDK & DON

[Diagram showing the results for Severity, FDK, and DON for different samples (F10.5, F11.2, WesleyBC6, WesleyBC70).]
• Tillers may not have higher contribution to total DON
Acknowledgements

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• NDSU: S. Halley, P. Gross, R. Brueggeman, R. Horsley
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• Jeffrey Stein (previously SDSU)
• Larry Osborne (previously SDSU)
• Charla Hollingworth (previously UMN-Crookston)
• SM Neate (previously NDSU)
• C. Nelson (previously SDSU)
Receiver operating characteristic (ROC) curves for the logistic regression models 3, 4, and 6. Sensitivity (TPP) represents the proportion of true classification of positive eDON events and specificity (TNP) represents the proportion of true classification of negative eDON events.
Results
Barley grains – Test wt. & yield

![Barley grains test weight and yield graph]

- **F10.5**
  - Test Weight: 115 kg/ha
  - Yield: 110 kg/ha

- **F11.2**
  - Test Weight: 120 kg/ha
  - Yield: 125 kg/ha

- **Quest**
  - Test Weight: 110 kg/ha
  - Yield: 115 kg/ha

- **Robust**
  - Test Weight: 125 kg/ha
  - Yield: 120 kg/ha

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**Legend:**
- **Test Weight**
- **Yield**

**Yield (kg/ha):**
- 125
- 120
- 115
- 110
- 105
- 100

**Test weight (g):**
- 1000
- 900
- 800
- 700
- 600
- 500
- 400
- 300
- 200
- 100
- 0
Results

SW – Test wt. & yield

![Graph showing test weight and yield for different samples. The graph compares test weight (g) and yield (kg/ha) for samples F10.5, F11.2, SD3854, and Brick. The data indicates a higher yield for F11.2 compared to F10.5 and SD3854.]

- **Test weight (g):**
  - F10.5: 150 (SD3854: 120)
  - F11.2: 200 (SD3854: 180)

- **Yield (kg/ha):**
  - F10.5: 300 (SD3854: 250)
  - F11.2: 350 (SD3854: 300)

- The graph shows that F11.2 has a significantly higher yield compared to F10.5 and SD3854.
Results

WW – Test wt. & yield

<table>
<thead>
<tr>
<th>Test weight (g)</th>
<th>Yield (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>F10.5 Wesley BC6</td>
<td>590 ± 10</td>
</tr>
<tr>
<td>F11.2 Wesley BC6</td>
<td>580 ± 10</td>
</tr>
<tr>
<td>F10.5 Wesley BC70</td>
<td>600 ± 10</td>
</tr>
<tr>
<td>F11.2 Wesley BC70</td>
<td>590 ± 10</td>
</tr>
</tbody>
</table>