The need to go beyond the pathogen in development of effective disease control strategies for sorghum

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A widely accepted current concept:

1. pathogen colonizes a host
2. responds to the host environment
3. resulting in the manipulation of expression of its resistance genes (Lamichhane and Venturi)

As a result:

- specialist pathogens have become the major focus in plant pathology
- virulent on a narrow host range
- often limited to a single species or genus
Most known plant genes for resistance to specialist pathogens confer qualitative resistance through innate immunity via large-effect loci that enable the recognition of the pathogen (Dangl and Jones 2001, Jones and Dangl 2006)

Studies have demonstrated this type of host–pathogen interaction in mono-species infections to the point of being race specific, e.g. wheat rusts.
The Result:

- Most plant pathology research is biased towards plant interactions with biotypes

- Associated with these are our concepts of co-evolution, PAMPs, gene for gene responses ....
Where am I going with this?

Populations of less specialized pathogens:

have a mixed population providing a mixture of selectivity

interactions with one another including
antagonism
synergism
co-existence
mutualism
co-operation……..

The level of disease damage depends on these interactions and corresponding host responses
There is a range of population diversity:
- within species
- mixed-species communities

E.g.

Genome-wide association (GWA) mapping: *B. cinerea*
- highly polygenic collection of genes
- breeding would need to utilize a diversity of isolates to capture all possible mechanisms
Generalist pathogens

- virulent across a wide range of plant host species
- have latent pathogenic capacities
- cause disease when host conditions are suitable

i.e.

may become pathogenic should host physiological conditions change (Hentschel et al., 2000)
This is where **agronomics** becomes more important than **genes**

Where am I going with this?

Enter ➔ Epidemiology

⇒ Systems analysis
In an epidemic, the basic system is the interaction between host and pathogen (Kranz and Hau, 1980)

This system's behaviour is defined by the environment

Thus, there are numerous interlocking processes characterized by many reciprocal cause-effect pathways (Watt 1966)

The environment too consists of systems and these systems interact and affect the behaviour of one another
Hierarchical Approach to Systems:

In the systems approach the host and pathogen are themselves considered systems i.e. dynamic

1. Growth
2. Physiology
3. Anatomy
4. New organs
5. Canopy density

1. Survival
2. Proliferation
3. Structures
   - sexual stages
   - asexual stages
     • conidia
     • chlamydospores
     • sclerotia
4. Races

Host - Pathogen
Disease
Hierarchical Approach to Systems:

- Host - Pathogen
- Disease
- Weeds
- Insects
- Other diseases

Biological constraint system

Reservoir for pathogens
Host stress - predisposition

Vectors – spread
Host stress - predisposition

Photosynthetic stress
- predisposition
Hierarchical Approach to Systems:

- Host - Pathogen
- Weeds
- Insects
- Other diseases
- Biological constraint system
- Chemical control
- Pest management system
Hierarchical Approach to Systems:

- **Host - Pathogen**
- **Weeds**
- **Insects**
- **Other diseases**
- **Biol constraint system**
- **Pest management system**
- **Crop management system**

- **Biological Control**
- **Chemical control**

- **Variety**
- **Fertilizer**
- **Cultural practices**
- **Crop sequence**
- **Economy**
- **Information psychology**
The need to go beyond the pathogen!!!!!
Relevance to sorghum pathology

E.g.: Seedling blights and root rot of sorghum

<table>
<thead>
<tr>
<th>Locality</th>
<th>Stand loss (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delmas</td>
<td>42.80</td>
</tr>
<tr>
<td>Dover</td>
<td>53.70</td>
</tr>
<tr>
<td>Heilbron</td>
<td>38.10</td>
</tr>
<tr>
<td>Koster</td>
<td>28.90</td>
</tr>
<tr>
<td>Koppies</td>
<td>69.20</td>
</tr>
<tr>
<td>Standerton</td>
<td>58.30</td>
</tr>
</tbody>
</table>
### Seedling blights and root rot of sorghum

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Root rot severity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PAN8706W</td>
<td>29.09</td>
</tr>
<tr>
<td>PAN8534</td>
<td>29.23</td>
</tr>
<tr>
<td>PAN8648W</td>
<td>29.60</td>
</tr>
<tr>
<td>PAN8229</td>
<td>45.42</td>
</tr>
<tr>
<td>PAN8389</td>
<td>45.60</td>
</tr>
<tr>
<td>PAN8568</td>
<td>47.00</td>
</tr>
</tbody>
</table>

**Equation:**

\[ Y = 58.674X^{0.1884} \]

**Coefficient of Determination:**

\[ R^2 = 0.73 \]
### Seedling blights and root rot of sorghum

#### Pathogen complex

<table>
<thead>
<tr>
<th>Pathogen</th>
<th>Source/Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Macrophomina phaeoleolina</td>
<td></td>
</tr>
<tr>
<td>Periconia circinata</td>
<td></td>
</tr>
<tr>
<td>Colletotrichum graminicola</td>
<td></td>
</tr>
<tr>
<td>Pyrenochaeta terrestris</td>
<td></td>
</tr>
<tr>
<td>Rhizoctonia solani</td>
<td></td>
</tr>
<tr>
<td>Fusarium moniliforme (sensu lato)</td>
<td>Pande and Karunakar, 1992</td>
</tr>
<tr>
<td>Pythium spp.</td>
<td></td>
</tr>
<tr>
<td>Sclerotium rolfsii</td>
<td></td>
</tr>
<tr>
<td>Erwinia spp</td>
<td>(Tarr, 1962)</td>
</tr>
<tr>
<td>F. graminearum (sensu lato)</td>
<td></td>
</tr>
<tr>
<td>F. equisetti</td>
<td></td>
</tr>
<tr>
<td>F. solani</td>
<td></td>
</tr>
<tr>
<td>Alternaria spp.</td>
<td></td>
</tr>
<tr>
<td>P. sorghina</td>
<td></td>
</tr>
<tr>
<td>Curvularia trifolii</td>
<td></td>
</tr>
<tr>
<td>F. oxysporum</td>
<td>(Reed et al., 1983; Windels and Kommedahl, 1984)</td>
</tr>
<tr>
<td>F. temperatum</td>
<td></td>
</tr>
<tr>
<td>Phoma macrostoma</td>
<td></td>
</tr>
<tr>
<td>Acremonium strictum</td>
<td></td>
</tr>
<tr>
<td>Colletotrichum capsici</td>
<td>(Van Rooyen, 2012)</td>
</tr>
</tbody>
</table>

#### Minor pathogens (Salt, 1979) – opportunists; host-stress related
Seedling blights and root rot of sorghum

- Complex of soil-borne pathogens
- Destroy the root structure and volume
  - reduce water and nutrient uptake
  - reduce plant vigour
  - lodging
- Reduced grain yield (up to 25%)
- Reduced quality

Distinct aerial symptoms not always visible
Seedling blights: driving variables (temperature)

![Graph showing incidence and damping-off against minimum temperature.]

- Incidence (%)
- Pre-em.damp.-off
- Post-em.damp.-off

Minimum temperature (°C)

- y = 3E+13x^{-4.94}
- R² = 0.51

Planting date (DOY)
Seedling blights: driving variables (Acid saturation; pH)

- Mesocotyl discoloration (%)
  - Equation: $Y = 16.6X^{0.201}$
  - $R^2 = 0.87$

- Secondary root discoloration (%)
  - Equation: $Y = 1.33E4X^{-3.883}$
  - $R^2 = 0.64$

- Acid saturation (%)

- pH (KCl)
## Root rot: driving variables (soils)

### Correlation coefficients - nutrient elements

<table>
<thead>
<tr>
<th></th>
<th>Root volume</th>
<th>Root rot</th>
<th>Yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>0.04</td>
<td>-0.41</td>
<td>0.36</td>
</tr>
<tr>
<td>C</td>
<td>-0.11</td>
<td>-0.47</td>
<td>-0.02</td>
</tr>
<tr>
<td>Ca</td>
<td>0.62</td>
<td>-0.61</td>
<td>0.36</td>
</tr>
<tr>
<td>Mg</td>
<td>0.64</td>
<td>-0.81</td>
<td>0.37</td>
</tr>
<tr>
<td>K</td>
<td>0.36</td>
<td>-0.64</td>
<td>0.23</td>
</tr>
<tr>
<td>Fe</td>
<td>-0.31</td>
<td>0.84</td>
<td>-0.38</td>
</tr>
<tr>
<td>Cu</td>
<td>-0.45</td>
<td>0.21</td>
<td>-0.57</td>
</tr>
<tr>
<td>Zn</td>
<td>0.07</td>
<td>0.01</td>
<td>-0.13</td>
</tr>
<tr>
<td>Mn</td>
<td>0.15</td>
<td>-0.31</td>
<td>-0.03</td>
</tr>
<tr>
<td>P</td>
<td>0.81</td>
<td>-0.95</td>
<td>0.92</td>
</tr>
</tbody>
</table>

(McLaren, 2004)
## Root rot: driving variables (inherent root volume)

<table>
<thead>
<tr>
<th></th>
<th>Root rot severity (%)</th>
<th>Root volume per plant (ml)</th>
<th>Effective root volume (ml)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>5 most susceptible</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PAN8389</td>
<td>45.60</td>
<td>10.89</td>
<td>5.92</td>
</tr>
<tr>
<td>PAN8229</td>
<td>45.42</td>
<td>13.44</td>
<td>7.34</td>
</tr>
<tr>
<td>PAN8625</td>
<td>44.82</td>
<td>4.86</td>
<td>2.68</td>
</tr>
<tr>
<td>PAN8568</td>
<td>43.80</td>
<td>21.67</td>
<td>12.18</td>
</tr>
<tr>
<td>PAN8157</td>
<td>42.69</td>
<td>18.61</td>
<td>10.67</td>
</tr>
<tr>
<td><strong>5 most resistant</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PAN8353</td>
<td>32.62</td>
<td>12.17</td>
<td>8.20</td>
</tr>
<tr>
<td>PAN8556</td>
<td>31.18</td>
<td>15.78</td>
<td>10.86</td>
</tr>
<tr>
<td>PAN8648W</td>
<td>29.53</td>
<td>17.40</td>
<td>12.26</td>
</tr>
<tr>
<td>PAN8706W</td>
<td>29.42</td>
<td>7.13</td>
<td>5.03</td>
</tr>
<tr>
<td>PAN8534</td>
<td>29.23</td>
<td>20.42</td>
<td>14.45</td>
</tr>
<tr>
<td>LSD P&lt;0.05</td>
<td>5.77</td>
<td>5.21</td>
<td>2.83</td>
</tr>
</tbody>
</table>
# Root rot: driving variables (rotations systems)

<table>
<thead>
<tr>
<th>Preceding crop</th>
<th>Root mass (g)</th>
<th>Root rot rating (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NS5511</td>
<td>PAN 8706W</td>
</tr>
<tr>
<td>Fallow</td>
<td>142.80</td>
<td>145.80</td>
</tr>
<tr>
<td>Monocult</td>
<td>95.60</td>
<td>112.00</td>
</tr>
<tr>
<td>Dry Bean</td>
<td>231.90</td>
<td>198.50</td>
</tr>
<tr>
<td>Cow Pea</td>
<td>313.10</td>
<td>182.90</td>
</tr>
<tr>
<td>Soybean</td>
<td>283.30</td>
<td>180.10</td>
</tr>
<tr>
<td>Mean</td>
<td><strong>193.30</strong></td>
<td><strong>163.90</strong></td>
</tr>
</tbody>
</table>
## Root rot: driving variables (rotations systems)

<table>
<thead>
<tr>
<th>Preceding crop</th>
<th>Effective root mass (g)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NS 5511</td>
<td>PAN 8706W</td>
</tr>
<tr>
<td>Follow</td>
<td>69.12</td>
<td>104.54</td>
</tr>
<tr>
<td>Monoculture</td>
<td>58.99</td>
<td>76.61</td>
</tr>
<tr>
<td>Dry Bean</td>
<td>131.49</td>
<td>162.17</td>
</tr>
<tr>
<td>Cow Pea</td>
<td>182.85</td>
<td>152.54</td>
</tr>
</tbody>
</table>

\[ y = 707.99e^{0.0077x} \]

\[ R^2 = 0.57 \]

(McLaren, 2004)

(Van Rooyen, 2018)
Thus...

Disease management lies with an integration of:

Host characteristics $\rightarrow$ root volume
Soil condition $\rightarrow$ pH; nutrients
Temperature $\rightarrow$ planting date
Crop rotation $\rightarrow$ nutrients; root volume

Soil organic matter content $\rightarrow$ biodiversity; suppression
Stubble management $\rightarrow$ survival; suppressive organisms
Herbicide management $\rightarrow$ chemical stress management

Highlights the importance of epidemiology and systems analysis!!

The need to go beyond the pathogen – disease control strategies
Root rot: driving variables (GxE interactions)

Deviation from the mean ergosterol levels

G1 – BTX 378
G2 – BTX 3197
G3 – RTX 430
G4 – RTam 428
G5 – RTX 436
G6 – BTX 635
G7 – BTX ARG-1
G8 – RTX 2917
G9 – SC 630-11EII
G10 – SC 630-11Eu
G11 – SC 748-5
G12 – SC 109-14E
G13 – SC719-11E
G14 – SC103-12E
G15 – Dobbs
G16 – Hegari
G17 – RTam 2566
G18 – TX 2911
G19 – SCAY 13
G20 – SCAY 16
G21 – SCAY 21
G22 – SCAY 14
E1 – Cedara 2009/10
E2 – Cedara 2010/11 (1)
E3 – Cedara 2010/11 (2)
E4 – Cedara 2011/12 (1)
E5 – Cedara 2011/12 (2)
E6 – Alma 2012/13 (1)
E7 – Alma 2012/13 (2)
E8 – Alma 2013/14
Ergot of Sorghum

• A disease of unfertilized ovaries

• Incidence and severity $\propto$ pollen availability

• Pollen viability $\propto$ pre-flowering cold stress
Ergot of Sorghum

PAN8564

\[ Y = 69.7X - 2.33X^2 - 424.78 \]

\[ R^2 = 0.62 \]

NK283

\[ Y = 1.33X \]

\[ R^2 = 0.83 \]

Mean minimum temperature (°C)

(days 23-27 pre-flowering)

Viable pollen (%)
Ergot of Sorghum

Observed ergot severity (%)

Ergot potential (%)

Y = 8.71X^{0.56}
EBP = 0.37

Y = 0.18E^{-4}X^{4.62}
EBP = 15.11
Disease management lies in:

- avoiding pollen viability
- reducing conditions
- selecting for escape resistance in genotypes

i.e. beyond the pathogen
Sorghum grain molds

Numerous fungi

- Diversity between species
- Interactions – inhibition, co-habitation
- Co-incident with seasonal conditions

*Alternaria alternata*
*Colletotrichum graminicola*
*Curvularia lunata*
*Fusarium thapsinum*
*F. semitectum*
*Phoma sorghina*

(Singh and Bandyopadhyay, 2000)
Sorghum grain molds

Isolation frequency (%)

- Fusarium graminearum
- Phoma sorghina
- Fusarium thapsinum
- Alternaria spp.
- Epicoccum nigrum
- Curvularia trifolii
- Bipolaris sorokiniana
- Cladosporium spp.

Cedara 2009-2012
# Sorghum grain molds

<table>
<thead>
<tr>
<th>Species</th>
<th>Locality</th>
<th>Crop</th>
<th>DON</th>
<th>NIV</th>
<th>3-ADN</th>
<th>15-ADN</th>
<th>NIV</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>F. boothii</em></td>
<td>W’fontein</td>
<td>Maize</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td><em>F. boothii</em></td>
<td>F‘fort</td>
<td>Maize</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td><em>F. boothii</em></td>
<td>B’ lehem</td>
<td>Maize</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td><em>F. meridionale</em></td>
<td>Cedara</td>
<td>Sorghum</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td><em>F. meridionale</em></td>
<td>P’stroom</td>
<td>Sorghum</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td><em>F. cortaderiae</em></td>
<td>Cedara</td>
<td>Sorghum</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td><em>F. acaciae-mearnsii</em></td>
<td>Cedara</td>
<td>Sorghum</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td><em>F. meridionale</em></td>
<td>P’stroom</td>
<td>Sorghum</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>+</td>
</tr>
</tbody>
</table>

The table above shows the results of a study on Sorghum grain molds using FGSC chemotypes. The table lists the species, locality, crop, and the presence or absence of specific compounds (DON, NIV, 3-ADN, 15-ADN, NIV) when using ToxP1/ToxP2 primers and Tri12 primers.
Sorghum grain molds

- Tissue specific
- Superficial e.g. *Phoma sorghina* *Alternaria alternata* *Colletotrichum graminicola*
- Deep seated e.g. *F. graminearum* (sensu lato)

\[
Y = (510.606251513941) + ((282.313429813325) - (510.606251513941))/(1+(347977.182760671)*\text{EXP}(-(.38871573656899)\cdot x))
\]

\[R^2 = 0.99\]
Sorghum grain molds

Model:
PC1 = 55%
PC2 = 32%

Fungus Genotypes:
A. alternata
C. lunata
F. graminearum
F. thapsinum
P. sorghina

Genotypes:
1
2
3
4
5
6
7
8
9
10
11

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Sorghum grain molds

Control

flowering date management (similar to ergot)

rotations

biotic factors - insects

\[
\text{NK283: } Y = 15.21X + 21.64, \quad R^2 = 0.91
\]

\[
\text{PAN8706W: } Y = 16.93X + 16.25, \quad R^2 = 0.78
\]

\[
\text{NK283: } Y = 10.26X + 7.19, \quad R^2 = 0.78
\]

\[
\text{PAN8706W: } Y = 3.40X + 11.33, \quad R^2 = 0.78
\]
The need to go beyond the pathogen in development of effective disease control strategies for sorghum
Systems analysis

- Allows for improvement of strategic and tactical decision making in crop protection
  - based on statistical quantification of relationships between variables
Ergot Potential of a flowering date

\[ Y = (-3.229 \times X_1) \]

(pre-flowering cold stress)

(days 23-27 pre-flowering)

\[ + \]

\[ \exp(-0.0029 \times X_2^2 + 0.0936 \times X_2 + 3.061) \]

(daily maximum temp.)

(days 1-4 post-anthesis)

\[ + \]

\[ 0.379 \times X_3 \]

(daily maximum RH)

(days 1-4 post-anthesis)

Index of agreement \( d = 0.94 \)
Ergot Potential of a flowering date

Day of year

Ergot incidence (%)
Grain molds

\[ FgSC = 216.86 \text{MaxRH}_{82-95} - 746.75 \text{MaxT}_{82-95} \quad R^2 = 0.79 \]

\[ \text{DON}=0.06FgSC-0.035\text{MaxT}_{101-115} \quad R^2=0.84 \]

\[ \text{NIV}=3.68E-05FgSC+2.99E-03\text{MinT}_{91-104} \quad R^2=0.83 \]

\[ \text{ZEA}=7.12E-03FgSC+0.26\text{MinT}_{100-113} \quad R^2=0.92 \]
Fumonisin production by *F. verticillioides*

\[ Y = \frac{31.90}{(1 + ((x - 90.69)/52.66)^2)} \times (1 + ((y - 29.80)/2.11)^2) \]

\[ R^2 = 0.86 \]
Going beyond the pathogen

Allows for improvement of **strategic** and **tactical** decision making in **crop protection**

- based on **statistical quantification** of relationships between variables
- describes **system behavior** (quantitative)
- the current state of the system can be used to make projections
- **improved epidemiological** knowledge – **improved decision making** for producers
Thank You
Dankie

THE SORGHUM TRUST