

Supplementary Materials

[illegible]

S1: Graphical representation of the 0.35 acres where the RCBD split plots were planted for the trials conducted at the Volga research station. Note that the South shore had similar experimental design. 1-12 are the seed treatments, A1 and A2 are the cultivars, 101-112 are the plots in block 1, 201-212 are the plots in block 2, 301-312 are the plots in block 3, and 401-412 are the plots in block 4. Each block is a replication hence we had 4 replications for each of the sowing times.

S2: Doses of seed dressing fungicides used in the greenhouse, growth chamber and field per 100 kg of Grain, Active Ingredients, and the corresponding water volumes for seed coverage, and associated FRAC groups

Treatment (Trade Name)	Manufacturer	Active Ingredient	^a FRAC Group	Fungicide (mL/100 kg)	Water (mL)
Evergol® Energy	Bayer Crop Science (Research Triangle Park, NC)	Prothioconazole (7.18%), Metalaxyl (5.74%), Penflufen (3.59%)	3, 4, 7	65.06	130
Vibrance® 500 FS	Sygenta	Sedaxane (43.17%)	7	4.82	10

Stamina®	BASF (Research Research Triangle Park, NC)	Pyraclostrobin (18.4%)	11	26.51	53
*Stamina F3®	BASF (Research Triangle Park, NC)	Pyraclostrobin (1.59%), triticonazole (1.59%), and Metalaxyl (0.93%)	11, 3, 4	26.51	53
Rancona® Pinnacle	UPL NA inc.	Ipconazole (4.48%), Metalaxyl (3.1%)	3, 4	325.3	650
Dividend® Extreme	Sygenta	Difenoconazole (7.73%), Metalaxyl (1.93%)	3, 4	259.24	518
*Warden Cereals WR11®	WinField United	Thiamethoxam (5.75%), Difenoconazole (3.45%), Mefenoxam (0.86%), Fludioxonil (0.72%), Sedaxane (1.44%)	4A, 3, 4, 12, 7	260.79	150

*Fungicide Review and Action Committee

*Used in greenhouse studies. The rest were used only in the field studies but note that most of these have a combination of more than one active ingredient.

S3. Statistical models used in the study and including their assumptions and terms

1. Greenhouse studies

Model: $\{Y_{ijkl}\} = \mu + T_i + C_j + R_k + T_i C_j + \epsilon_{ijkl}$

Description of model terms

Y_{ijkl} : Observed response (disease severity, lesion count, lesion size).

μ : Overall mean.

T_i : Fixed effect of fungicide seed treatment ($i=1, \dots, n$).

C_j : Fixed effect of cultivar ($j=1, \dots, m$).

R_k : Random effect of experimental run(replication) ($k=1, 2, \dots, p$).

$T_i C_j$: Interaction between fungicide seed treatment and cultivar.

ϵ_{ijkl} : Random error ($\epsilon_{ijkl} \sim N(0, \sigma^2)$).

Assumptions

- Errors (ϵ_{ijkl}) are independently and normally distributed with a mean of 0 and constant variance.
- Random effects are independent of fixed effects.
- Homogeneity of variance across treatments and cultivars (tested using Levene's test).

2. Field studies

Model: $\{Y_{ijklm}\} = \mu + C_i + T_j + L_k + P_l + (C_i T_j) + (T_j L_k) + (C_i P_l) + R_m(L_k) + \epsilon_{ijklm}$

Description of model terms

Y_{ijklm} : Observed response (e.g., disease severity, plant density, grain yield).

μ : Overall mean.

C_i : Fixed effect of cultivar ($i=1, 2$).

T_j : Fixed effect of fungicide seed treatment ($j=1, \dots, n$).

L_k : Random effect of location ($k=1, 2$).

P_l : Fixed effect of sowing time ($l=1, 2$).

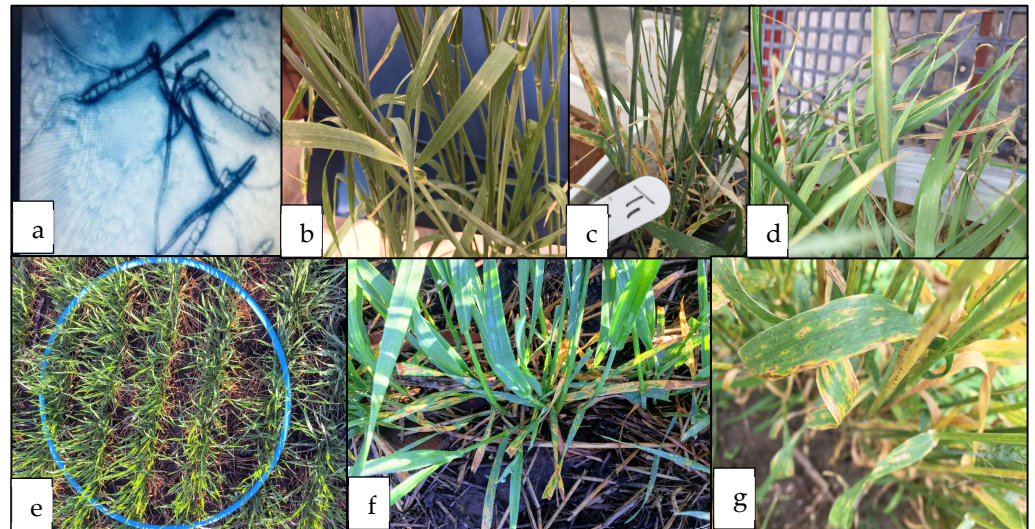
$R_m(L_k)$: Random effect of replication nested within location ($m=1, \dots, t$).

$C_i T_j$, $T_j L_k$, $C_i P_l$: Interaction terms.

ϵ_{ijklm} : Random error ($\epsilon_{ijklm} \sim N(0, \sigma^2)$)

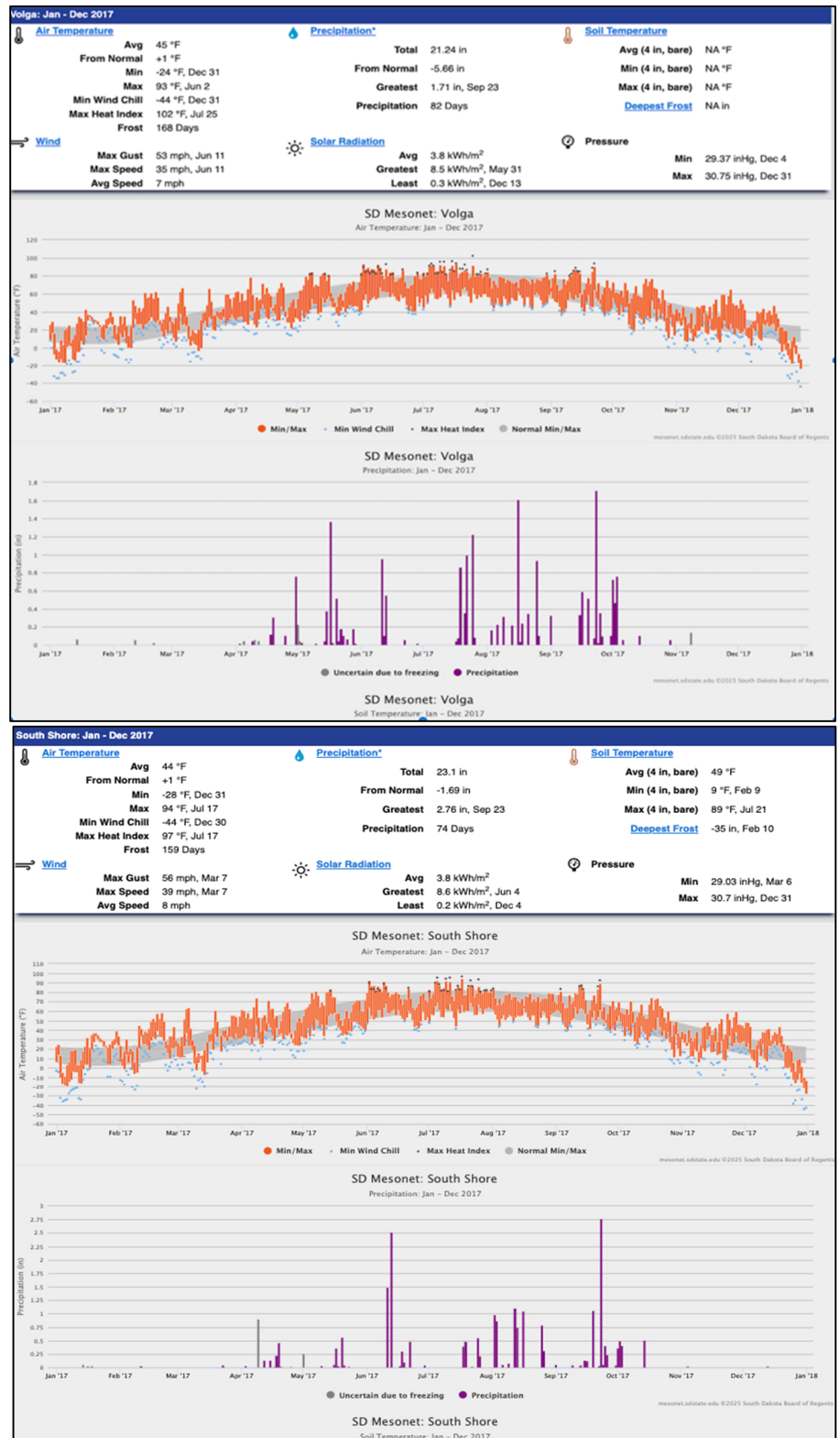
Assumptions:

- Errors (ϵ_{ijklm}) are independently and normally distributed with constant variance.
- Random effects are independent of fixed effects.
- Homogeneity of variance across locations, sowing times, treatments, and cultivars.



S4: Images with disease symptoms from the greenhouse, growth chamber and field studies on tan spot and stripe rust diseases

- a) Spores of *P. tr* used for greenhouse inoculation
- b) Inoculated and treated wheat plants with visibly less tan spot symptoms
- c) Wheat plants (control) with visible tan spot on the lower leaves
- d) Wheat plants with stripe rust symptoms following growth chamber inoculation
- e) Field plant density counts using a hula hoop
- f) Early tan spot symptoms on the lower leaves in the field
- g) Late tan spot symptoms on the upper leaves in the field



S5: Climate data visualization for Volga and South Shore where the field experiments were conducted (Data from South Dakota Mesonet, South Dakota)

State University (2025). SD Mesonet Archive. Retrieved from
<https://mesonet.sdstate.edu/archive>)