Wheat Variety Response to Seed Cleaning and Treatment after Fusarium Head Blight Infection

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Core Ideas
- We evaluated wheat stand and yield response to seed cleaning and treatment.
- Seed was sourced from a season with severe head scab infestation.
- Seed cleaning increased stand count, yield, and test weight.
- Varieties responded to seed cleaning differently depending on yield potential.
- Seed treatment increased grain yield and 1000-kernel weight.

ABSTRACT
Wheat yield response to seed cleaning and chemical treatment is inconsistent and may reflect the nature of the seed used for sowing. Thus, yield responses might exist after severe incidence of Fusarium head blight (FHB). Our objective was to evaluate seed cleaning and seed treatment effects on three wheat varieties with different levels of tolerance to FHB after a season with severe FHB infection. Field experiments occurred during the 2015–2016 and 2016–2017 growing seasons in Manhattan, KS. The treatment structure was a 3 × 3 × 2 complete factorial in a randomized complete block design with four replications. The treatments consisted of three wheat varieties (‘Everest’, moderately tolerant to FHB; and ‘WB Grainfield’ and ‘SY Wolf’, moderately susceptible to FHB), three seed cleaning intensities (gravity table, air screen, and control), and two seed treatments (insecticide + fungicide vs. control). Seed cleaning increased stand count, yield, and test weight. For yield, however, there was a significant variety × seed cleaning interaction: the variety WB Grainfield responded to seed cleaning (~4.1 Mg ha⁻¹ under the gravity table), whereas the other varieties did not. Seed treatment increased grain yield (+0.3 Mg ha⁻¹) and 1000-kernel weight. Protein concentration was inversely proportional to grain yield, and Everest had the highest protein concentration (~13%) in comparison with WB Grainfield and SY Wolf, even when corrected for the same yield level. These results suggest that seed treatment can increase grain yield when using seed from a season with severe FHB infestation, but yield responses to seed cleaning are variety specific.

Abbreviations: FHB, Fusarium head blight.

Wheat (Triticum aestivum L.) is one of the most widely cultivated crops in the world, accounting for ~29% of the world’s cereal production (USDA, 2018a). The United States is the world’s fourth largest wheat producer, with ~63 MMt of wheat produced annually on 51 Mha (FAO, 2018). The United States also stands out as the world’s largest wheat exporter, with over 27 MMt exported per year, which accounts for about 15% of the world’s wheat exports (USDA, 2018c). Approximately 70% of all the wheat area in the United States is planted to winter wheat (USDA, 2018b), and the main winter wheat–producing region is in the Great Plains (USDA, 2018a), which includes the states of Kansas, Oklahoma, Texas, Colorado, Nebraska, South Dakota, and Wyoming.

Wheat grain yield is directly related to abiotic (i.e., climate and soil) and biotic factors (i.e., insects and diseases). Among the biotic factors, Fusarium head blight (FHB), or head scab, a disease caused by the fungi Fusarium graminearum Schwabe sensu lato and F. culmorum, (Wm.G.Sm) Sacc., is one of the main concerns of wheat producers in the central and eastern regions of the US Great Plains (Osborne and Stein, 2007). Head scab causes damage to the spikes and grains, directly compromising wheat productivity, quality for baking and consumption, and the physiological quality of the seed (Miedaner, 1997). Thus, FHB results in direct economic losses, including reduced yield and quality of grains (e.g., aborted seeds or reduced seed size or grade reduction) and causes indirect losses due to contamination by trichothecene mycotoxins (McLeod, 1993), such as deoxynivalenol, which is toxic to animals and humans (Desjardins et al., 1993).
Foliar fungicides can help control FHB. However, their efficacy is inconsistent (Howard et al., 1994). For example, only a few active ingredients (e.g., metconazole, prothioconazole, and tebuconazole) offer a certain level of control (Avozani et al., 2014), and application should occur in the 10-d period surrounding anthesis (Dill-Macky et al., 2012). This short window of application is challenging, especially in growing seasons where excessive rainfall and consequently moist soils occurs around anthesis and thus preclude ground-based fungicide application. Therefore, in areas prone to head scab, it is recommended to use a combination of avoiding host-on-host rotations, to use varieties that are less susceptible to FHB, and to apply a well-timed foliar fungicide at anthesis (McMullen et al., 2008, 2012; Paul et al., 2019; Wegulo et al., 2011). The genetic resistance of a wheat variety can help reduce the damage levels of head scab, both as improved grain yield and grain quality (Bai and Shaner, 2004). However, in years in which the weather is conducive to FHB incidence, crop productivity and seed quality may also be impaired in tolerant varieties, affecting the establishment of subsequent crop (Brennan et al., 2006). Under these conditions, seed cleaning and fungicide treatment can help to improve seed germination, stand establishment, and ultimately crop productivity.

Wheat seed cleaning typically consists of air screening followed by gravity table; both processes can affect seed size (Peske et al., 2012), wheat forage, and grain yield (Edwards and Krenzer, 2006). Weimareck (1975) reported that large seeds had better germination than medium and small seeds and that large seedlings had a higher survival rate than smaller seeds under field conditions. In addition, seed size is correlated with vigor, and larger seeds tend to produce more vigorous seedlings (Ries and Everson, 1973). Thus, quality control measures are important to maximize wheat yield in a region such as the US southern Great Plains, where the quality of farmer-saved seed is variable (Edwards and Krenzer, 2006). A complementary strategy to improve the chances of an appropriate crop establishment would include treatment of seed with fungicide. Fungicide seed treatments are designed to mitigate external or internal microorganisms from seeds or soil, resulting in a healthy seedlings and plants (Khanzada et al., 2002). Thus, seed can be treated to promote good stand establishment, minimize yield loss due to suboptimal seed quality, and limit the spread of pathogens, although fungicide seed treatment does not completely eliminate the risk of disease transmission (Beres et al., 2016; Khanzada et al., 2002; Turkington et al., 2016). However, the effects of seed treatment on grain yield are inconsistent, with previous research showing no yield gain (Kashyap et al., 1994) or a positive association with wheat yield (Lollato et al., 2018). Due to the inconsistent yield response and an increased cost of production, seed treatments have not been widely adopted among wheat producers (Kolling et al., 2012).

We conducted a study with the objective of evaluating different methods of seed cleaning and fungicide seed treatment for three winter wheat varieties with different levels of resistance to FHB, using grain collected from a growing season with a severe epidemic of *F. graminearum*.

**MATERIALS AND METHODS**

**Trial Location**

The experiment was conducted during the 2015–2016 and 2016–2017 winter wheat growing seasons at the North Farm Experimental Station at Kansas State University in Manhattan, KS (39°12’ N, 96°35’ W, 350 m asl) (Fig. 1). The soil is classified as Kahola silt loam (fine-silty, mixed, superactive, mesic Cumulic Hapludolls) (USDA–NASS, 2018), and the weather is temperate subhumid (Kottek et al., 2006). Average seasonal temperatures (maximum and minimum; °C) and cumulative precipitation (mm) were collected from a weather station from the Kansas Mesonet Network (http://mesonet.k-state.edu/) located about 100 m from the experiment and are presented in Table 1.

**Treatments and Experimental Design**

The experiment was established in a randomized complete block design with a 3 × 3 × 2 complete factorial treatment structure with four replicates. There were three winter wheat varieties: ‘Everest’, which is moderately tolerant to FHB, and ‘WB Grainfield’ and ‘SY Wolf’, which are moderately susceptible to FHB (DeWolf et al., 2008). There were three seed cleaning treatments (control, air screen, and gravity table) and two chemical seed treatments (treated or untreated). Seed from all varieties originated from neighboring fields and were collected during the 2015 harvest from north-central
Table 1. Average seasonal (i.e., fall, winter, spring) maximum and minimum temperatures and cumulative precipitation for the 2015–2016 and 2016–2017 growing seasons and historical data (1986–2016) in Manhattan, KS.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$T_{\text{max}}$</td>
<td>$T_{\text{min}}$</td>
<td>Precipitation</td>
</tr>
<tr>
<td>Fall</td>
<td>15.0</td>
<td>2.7</td>
<td>202.1</td>
</tr>
<tr>
<td>Winter</td>
<td>12.0</td>
<td>0.0</td>
<td>31.7</td>
</tr>
<tr>
<td>Spring</td>
<td>26.0</td>
<td>13.0</td>
<td>384.8</td>
</tr>
<tr>
<td>Average</td>
<td>18.0</td>
<td>4.6</td>
<td>–</td>
</tr>
<tr>
<td>Total</td>
<td>–</td>
<td>–</td>
<td>618.6</td>
</tr>
</tbody>
</table>


Kansas, a location-year that was characterized by the widespread occurrence of FHB resulting in 13.6% of losses on yield (Appel et al., 2015). Seeds were collected at three different time intervals in the seed cleaning process: (i) immediately after harvest (i.e., control), (ii) after air screening, and (iii) from the top of the gravity table. The air screening process occurred with a Delta 100 Super Cleaner (A/S Cimbria, Fårtoftvej) air cleaner equipped with pre-air and uplifting fan adjustments, with two levels of sifting (0.22-cm-diam. slots), followed by one level of scalpers (12.5 rounds) and another two levels of sifting (0.22-cm-diam. slots). The gravity table used was a Maxi Cap Gravity 4800 (Oliver Manufacturing). In this process, the seed mass stratification was made between lighter and heavier seeds (Martins et al., 1994), and only the heavier seeds were selected.

After seed cleaning, the seeds collected from each cleaning method were divided into two samples. One sample was used for the untreated control; the other sample was subjected to a chemical seed treatment. Seed treatment consisted of 100 mL of Gaucho XT seed treatment per 45.4 kg of seed, which corresponds to 26.9 g of imidacloprid (insecticide), 17.3 g of metalaxyl, and 13.1 g of tebuconazole (fungicides) per 100 kg of seed.

Crop Management

Sowing was performed under a no-tillage system following a previous maize crop at a seeding rate of 2.96 million seeds ha$^{-1}$ (Table 2). A composite soil sample consisting of 15 individual cores was collected at sowing to determine initial soil fertility for both the 0- to 15- and the 15- to 60-cm depths, and initial soil NO$_3$–N in the profile was used to calculate spring N rates (Table 3). Starter fertilizer was applied in-furrow with the seed at sowing across the entire experiment and consisted of 56 kg ha$^{-1}$ of diammonium phosphate (18–46–0). Spring fertilization consisted of broadcast urea (46–0–0) applied at spring greenup (Feekes GS 4). The N fertilization rate was calculated for a grain yield potential of 4.7 Mg ha$^{-1}$ using ~40 kg N ha$^{-1}$ for each Mg ha$^{-1}$ produced and crediting the total NO$_3$–N available in the profile at sowing, as well as N available from the in-furrow fertilizer and organic matter (Leikam et al., 2003), so the actual amount applied varied from year to year. Weeds were controlled with commercial herbicides, and 1.02 L ha$^{-1}$ of Quilt Xcel foliar fungicide was applied after flag leaf emergence, so foliar disease incidence was not a confounding factor. This corresponds to 13.7 g ha$^{-1}$ of azoxystrobin and 11.4 g ha$^{-1}$ of propiconazole. The experimental unit comprised an area of 9.7 × 1.5 m in the 2015–2016 season and 7.6 × 1.5 m in the 2016–2017 season. Row spacing was 0.19 m in both seasons.

Evaluations

Plant evaluations included stand count, grain yield, grain moisture, test weight, 1000-kernel weight, and grain protein concentration. Stand count was performed between 21 and 30 d after sowing and consisted of the number of plants emerged in one linear meter in the center rows at two different locations within each experimental unit. The average of the two measurements determined the final stand establishment for each plot. Grain yield and moisture content were determined by harvesting the entire experimental unit using a Massey Ferguson 8 XP (Kincaid Manufacturing). Test weight was assessed as the density of the grain expressed as kg hL$^{-1}$ (Ministério da Agricultura Pecuária e Abastecimento, 2009). Thousand-kernel weight was determined by counting and weighting 1000 kernels from the subsample of the harvested grains. Grain protein concentration (g kg$^{-1}$) was measured from the subsample collected during grain yield harvest using an infrared reflectance spectroscopy technique with a DA 7200 NIR analyzer (Perten Instruments). Grain yield, test weight, and grain protein were corrected to 13.5% moisture content.

Table 2. Sowing date, date of treatment application for topdress N and late fungicide, and harvest dates for experiment conducted during the 2015–2016 and 2016–2017 growing seasons in Manhattan, KS.

<table>
<thead>
<tr>
<th>Field operation</th>
<th>Growing season</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fungicide (Quilt Xcel)</td>
<td>22 Apr. 2016</td>
</tr>
<tr>
<td>Harvest</td>
<td>27 June 2016</td>
</tr>
</tbody>
</table>

Table 3. Soil analysis from the experimental area for the 2015–2016 and 2016–2017 growing seasons in Manhattan, KS.

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>pH</th>
<th>NO$_3$–N (mg dm$^{-1}$)</th>
<th>P (mg dm$^{-1}$)</th>
<th>K (mg dm$^{-1}$)</th>
<th>Ca (cmolc dm$^{-3}$)</th>
<th>Mg (cmolc dm$^{-3}$)</th>
<th>Na (mg dm$^{-1}$)</th>
<th>SO$_4$–S (mg dm$^{-1}$)</th>
<th>Cl (mg dm$^{-1}$)</th>
<th>CEC†</th>
<th>OM‡</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–15</td>
<td>6.6</td>
<td>9.7</td>
<td>39.8</td>
<td>210</td>
<td>4045</td>
<td>311</td>
<td>22.8</td>
<td>7.0</td>
<td>4.8</td>
<td>26.8</td>
<td>3.9</td>
</tr>
<tr>
<td>15–60</td>
<td>7.0</td>
<td>3.5</td>
<td>15.3</td>
<td>227</td>
<td>5383</td>
<td>279</td>
<td>23.9</td>
<td>4.4</td>
<td>3.3</td>
<td>23.1</td>
<td>–</td>
</tr>
<tr>
<td>0–15</td>
<td>7.8</td>
<td>9.7</td>
<td>19.6</td>
<td>304</td>
<td>5730</td>
<td>247</td>
<td>11.2</td>
<td>5.4</td>
<td>3.4</td>
<td>31.6</td>
<td>4.0</td>
</tr>
<tr>
<td>15–60</td>
<td>8.1</td>
<td>3.5</td>
<td>–</td>
<td>257</td>
<td>6691</td>
<td>265</td>
<td>16.0</td>
<td>3.6</td>
<td>3.6</td>
<td>36.4</td>
<td>3.3</td>
</tr>
</tbody>
</table>

† Cation exchange capacity.
‡ Organic matter.
Table 4. Thousand-kernel weight of each winter wheat variety after each seed cleaning method used at sowing in Manhattan, KS, during the 2015–2016 and 2016–2017 growing seasons.

<table>
<thead>
<tr>
<th>Variety</th>
<th>Control</th>
<th>Air screen</th>
<th>Gravity table</th>
</tr>
</thead>
<tbody>
<tr>
<td>Everest</td>
<td>28.8Ac†</td>
<td>29.88Bb</td>
<td>32.58Aa</td>
</tr>
<tr>
<td>SY Wolf</td>
<td>29.3Ac</td>
<td>34.0Ab</td>
<td>36.5Aa</td>
</tr>
<tr>
<td>WB Grainfield</td>
<td>26.2Bc</td>
<td>28.7Cb</td>
<td>32.08Aa</td>
</tr>
</tbody>
</table>

† Means followed by the same uppercase letter (varieties compared within seed cleaning method) or lowercase letter (seed cleaning method compared within variety) do not differ significantly from each other by the Holm–Sidak method at the 0.05 level.

Data Analysis

Seed size data as affected by variety and seed cleaning method were evaluated prior to establishing the experiment using a two-way ANOVA, with all pairwise multiple comparisons performed using the Holm-Sidak method in Sigma Plot 13 (Systat Software Inc.). Data collected from the experiment (i.e., stand count, grain yield, etc.) were analyzed using a three-way complete factorial ANOVA to evaluate the main effects (i.e., winter wheat variety, seed treatment, and seed cleaning method) along with the interactions using PROC GLIMMIX procedure in the SAS 10.2 statistical software (SAS Institute, Inc.). Because the difference between the mean residual squares for all the variables evaluated did not exceed the 7:1 ratio between years (data not shown), all results are shown as a combined analysis across both years (Pimentel-Gomes, 2009). Therefore, the model considered year and replication nested within year as random effects. Degrees of freedom were calculated using the Kenward–Roger's method (Littell et al., 2006). Least square means of significant treatment and interaction effects were compared using the piece-wise differentiable statement at the 0.05 probability level. Because grain protein concentration is dependent on yield level, a regression analysis was used to determine the relationship between grain yield and protein concentration. The residuals of this relationship were then analyzed to determine treatment effects on grain protein concentration (dependent variable) across a constant grain yield level (independent variable) (Latshaw et al., 2016; Sadras et al., 2017).

RESULTS

The different seed cleaning methods resulted in distinct 1000-seed weights for all varieties, measured prior to establishing the experiment (Table 4). The lowest seed size was consistently measured in the control treatment. Seed size increased by 1 to 4.7 g per 1000 kernels due to air screen, and gravity table increased seed size by an additional 2.5 to 3.3 g per 1000 kernels as compared with the air screen.

The combined ANOVA suggested a significant effect of seed cleaning on stand count as well as a significant effect of variety × seed cleaning interaction and seed treatment on grain yield (Table 5). For test weight, there were significant variety and seed cleaning effects; for 1000-kernel weight, the effect of variety was significant. For grain protein concentration, there was only a significant variety effect both when the raw data and the residual data from the grain yield relationship were analyzed (Table 5).

Plant stands ranged from 182 to 203 plants m⁻² for cleaning methods (Fig. 2), with the highest values resulting from the gravity table seed cleaning method (i.e., 202 plants m⁻²) and the lowest stand counts resulting from the control and air cleaning methods (i.e., 182 and 184 plants m⁻², respectively).

Grain yield was affected by the interaction of variety and seed cleaning method and by the main effect seed treatment (Table 5). Across varieties, WB Grainfield had the highest grain yield (4.1 Mg ha⁻¹); Everest and SY Wolf had significantly lower grain yield (3.5 and 3.6 Mg ha⁻¹) (Fig. 3). For WB Grainfield, gravity table increased grain yield to 4.4 Mg ha⁻¹, as compared with 4.1 and 3.8 Mg ha⁻¹ for the air cleaning and the control, respectively. However, SY Wolf and Everest did not respond to seed cleaning. Seed treatment increased grain yield by 0.3 Mg ha⁻¹ as compared with no seed treatment (Fig. 3).

Grain test weight was influenced only by variety and seed cleaning method (Table 5). Everest measured the highest test weight of 72.6 kg hL⁻¹ vs. WB Grainfield or SY Wolf; these weights were not significantly different from each other (Fig. 4). The gravity table seed
cleaning method increased test weight to 72 vs. 71.2 kg hL\(^{-1}\) from control; these weights were significantly different from each other. However, the air screening seed cleaning method resulted in a test weight of 71.6 kg hL\(^{-1}\), which was statistically similar to both control and gravity table. Thousand-kernel weight was affected by wheat variety (Table 5), with SY Wolf (28.6 g 1000 kernels\(^{-1}\)) and Everest (28.4 g 1000 kernels\(^{-1}\)) resulting in greater 1000-kernel weight as compared with WB Grainfield (27.2 g 1000 kernels\(^{-1}\)) (Fig. 5).

The raw data for grain protein concentration suggested that it was affected only by wheat variety (Table 5). Everest resulted in the highest protein concentration, followed by SY Wolf, which was also significantly higher than WB Grainfield (13, 12.5, and 11.8%, respectively) (Fig. 6). When regressed against grain yield, \~19\% of the variability in protein content was explained by the different grain yield levels (Fig. 7A), partially explaining the different levels of protein concentration among the varieties, because Everest and SY Wolf had lower yield than WB Grainfield. However, the residual analysis of protein concentration related to yield suggested that differences in protein content between varieties still occurred, even after normalizing the data for the same yield level (Fig. 7B).

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**Fig. 3.** Least square means for grain yield as affected by (A) the interaction between variety and seed cleaning and (B) seed treatment method for the 2015–2016 and 2016–2017 growing seasons in Manhattan, KS. For (A), lowercase letters are for comparisons of seed cleaning method within variety, and uppercase letters are for comparisons among varieties. Means followed by the same letter are not statistically different at \(P \leq 0.05\).

**Fig. 4.** Least square means of grain test weight for (A) variety and (B) seed cleaning methods for the experiments conducted during the 2015–2016 and 2016–2017 growing seasons in Manhattan, KS. Means followed by the same letter are not statistically different at \(P \leq 0.05\).

**Fig. 5.** Least square means of 1000-kernel weight for wheat varieties across both growing seasons (2015–2016 and 2016–2017) for the experiment conducted in Manhattan, KS. Means followed by the same letter are not statistically different at \(P \leq 0.05\).

**Fig. 6.** Least square means for grain protein concentration for the variety effect for the experiment conducted during the 2015–2016 and 2016–2017 growing seasons in Manhattan, KS. Means followed by the same letter are not statistically different at \(P \leq 0.05\).
Fig. 7. (A) Grain protein concentration as affected by grain yield and (B) the residuals of the aforementioned relationship as affected by variety for the experiment conducted during the 2015–2016 and 2016–2017 growing seasons in Manhattan, KS. In (B), means followed by the same letter are not statistically different at $P \leq 0.05$.

**DISCUSSION**

A large proportion of the wheat produced in the US southern Great Plains is sown with farmer-saved seed as a means to decrease production costs. Previous research has shown that wheat forage and grain yield might be similar between farmer-saved seed and certified seed if similar quality control measures are adopted (Edwards and Krenzer, 2006). However, in the current study we expanded on this knowledge by collecting seed from a region and growing season in which FHB was a prevalent problem (Appel et al., 2015). We studied the effects of variety selection (within the context of variety-specific susceptibility to FHB), seed cleaning processes (which ultimately affect seed size), and fungicide seed treatment on wheat yield, yield components, and protein content.

Improved seed cleaning showed clear benefits to stand establishment and to yield, with the latter depending on variety. According to Weimarck (1975), large seeds emerge better than medium and small seeds, and large seedlings have a higher survival rate than smaller seeds. Similar results were reported by Beres et al. (2016). Likewise, our results support those findings because larger seeds resulted in a greater number of plants established per unit area. According to Ries and Everson (1973), seed size is positively correlated with vigor, and larger seeds tend to produce more vigorous seedlings due to the larger size of the endosperm. However, Royo et al. (2006) reported no clear trend between more vigorous wheat seedlings and grain yield. Similarly, Mian and Nafziger (1992) and Chastain et al. (1995) reported that seed size had little effect on wheat yield. Likewise, our results are supported by the literature because the yield response to seed cleaning was variable and depended on variety. The wheat varieties Everest and SY Wolf yielded similarly under different levels of seed treatment, and WB Grainfield had a yield increase resulting from the different seed cleaning methods, with the gravity table (i.e., larger seeds) resulting in greater yield than air cleaning (i.e., intermediate seed size), followed by the uncleaned control (i.e., smaller seeds).

Another possible explanation for the WB Grainfield response to seed cleaning and the lack of response from other varieties could be the greater average yield within the context of this experiment as well as in the variety performance trials conducted about 100 m from our experiments during the 2015–2016 and 2016–2017 growing seasons (Lingenfelser et al., 2016, 2017). The magnitude of crop yield response from different agronomic crops to distinct management practices often depends on variety yield potential, usually with greater responses to management in more productive environments (Assefa et al., 2016; Cruppe et al., 2017; Lollato et al., 2019). Therefore, the cause of reduced seed size should be considered in future studies (Mian and Nafziger, 1992). Nonetheless, our study showed that a moderately susceptible variety to FHB with a high yield potential (Lingenfelser et al., 2016, 2017) resulted in the greatest yield in the season subsequent to a high FHB infestation. The response of the variety SY Wolf, which had a lower yield potential in our study and in the regional variety performance trials in the same location (Lingenfelser et al., 2016, 2017), was different and did not increase in response to seed cleaning. This suggests that FHB susceptibility might not be the leading factor when selecting a wheat variety from the perspective of seed quality as long as seed cleaning and chemical treatment ensure acceptable quality and the variety has a high yield potential. We note in passing, though, that the initial seed infection levels were not measured in this study, and seed germination test and percent of seed infection should be quantified in future work to further confirm our results. Additionally, none of the seasons evaluated (2015–2016 and 2016–2017) had FHB incidence (0.1 and 0.3% yield loss, respectively) (Hollandbeck et al., 2017), and therefore each variety’s yield response to in-season FHB was not evaluated (data not shown).

Further, seed size had little effect on wheat yield. Likewise, our results are supported by the literature because the yield response to seed cleaning was variable and depended on variety. The wheat varieties Everest and SY Wolf yielded similarly under different levels of seed treatment, and WB Grainfield had a yield increase resulting from the different seed cleaning methods, with the gravity table (i.e., larger seeds) resulting in greater yield than air cleaning (i.e., intermediate seed size), followed by the uncleaned control (i.e., smaller seeds).

According to Schinzel (1983), the gravity table is an alternative to improve wheat physical and physiological quality because it allows for the segregation of decayed, malformed, immature seeds as compared with healthy/normal seeds (Gregg, 1975). Thus, the greater yield measured in WB Grainfield with improvements in seed cleaning can be partially justified by larger seeds as compared with air screen or control (Chastain et al., 1995). Another factor that potentially allowed a greater response to grain cleaning in our experiment compared with other experiments evaluating only the effect of seed size was the head scab incidence during the harvest in which the seeds for the experiment were collected (Mian and Nafziger, 1994; Royo et al., 2006). Therefore, the cause of reduced seed size should be considered in future studies (Mian and Nafziger, 1992). Nonetheless, our study showed that a moderately susceptible variety to FHB with a high yield potential (Lingenfelser et al., 2016, 2017) resulted in the greatest yield in the season subsequent to a high FHB infestation. The response of the variety SY Wolf, which had a lower yield potential in our study and in the regional variety performance trials in the same location (Lingenfelser et al., 2016, 2017), was different and did not increase in response to seed cleaning. This suggests that FHB susceptibility might not be the leading factor when selecting a wheat variety from the perspective of seed quality as long as seed cleaning and chemical treatment ensure acceptable quality and the variety has a high yield potential. We note in passing, though, that the initial seed infection levels were not measured in this study, and seed germination test and percent of seed infection should be quantified in future work to further confirm our results. Additionally, none of the seasons evaluated (2015–2016 and 2016–2017) had FHB incidence (0.1 and 0.3% yield loss, respectively) (Hollandbeck et al., 2017), and therefore each variety’s yield response to in-season FHB was not evaluated (data not shown).

Another possible explanation for the WB Grainfield response to seed cleaning and the lack of response from other varieties could be its greater average yield within the context of this experiment as well as in the variety performance trials conducted about 100 m from our experiments during the 2015–2016 and 2016–2017 growing seasons (Lingenfelser et al., 2016, 2017). The magnitude of crop yield response from different agronomic crops to distinct management practices often depends on variety yield potential, usually with greater responses to management in more productive environments (Assefa et al., 2016; Cruppe et al., 2017; Lollato et al., 2019). There may be a greater response to seed processing in higher-yielding varieties and environments. However, this hypothesis has not been tested for wheat, leading to a possible study to be performed in future years.

Retrieving seed produced in a growing season with high FHB incidence may also have influenced the relatively high yield response to chemical seed treatment in our study, although seed treatments...
have previously increased grain yield in other studies (Beres et al., 2016; DeVuyst et al., 2014; Pike et al., 1993; Turkington et al., 2016). The chance of achieving a sufficient yield increase to cover the costs associated with seed treatment depends on the treatment costs (Esker and Conley, 2012), and sometimes even small increases in grain yield result in greater profitability in wheat (Cook et al., 2002). However, yield increases derived from seed treatments are variable and depend on a variety of biotic and abiotic factors (Gaspar et al., 2014), including the percent of seed infection prior to sowing. Overall, results of the current experiment are applicable to medium- to high-yielding wheat seasons for the region and were probably exacerbated by having collected seeds after an epidemic year in 2015, which is similar to results reported by Lollato et al. (2018). Future research could focus on quantifying the probability of yield gain and profit from seed cleaning and seed treatment across a wide range of environmental conditions, similar to the efforts of Beres et al. (2016), Gaspar et al. (2014), and Turkington et al. (2016).

Wheat grain protein content is determined by the discrepancy (or lack thereof) between the N requirement of the crop and the N supply to the crop as well as environmental conditions during grain filling (Goos et al., 1982; Lollato and Edwards, 2015; Lollato et al., 2019). For hard red winter wheat, protein concentrations >11.5% indicate that grain yield was not limited by total N available during the season (Goos et al., 1982). Therefore, N rates applied in our experiment were enough to maximize yield because the majority of the measured protein concentration values were >11.5%. However, yield and protein are often negatively correlated (Fettel et al., 2012; Lollato and Edwards, 2015; Lollato et al., 2019). Likewise, we observed that the variety Everest obtained higher protein but lower yield when compared with WB Grainsfield. Nonetheless, our analysis suggest that Everest naturally has a higher protein concentration than WB Grainsfield, as determined by the residual analysis (Latshaw et al., 2016). Similar results were reported by variety performance trials in which grain protein concentration was measured, conducted in the neighboring state of Oklahoma (i.e., Everest was positioned in the highest testing protein group in 3 out of 12 trials, whereas WB Grainsfield was never ranked in the highest protein group) (Marburger et al., 2016).

Differences in grain protein concentration were reported in a study developed by Latshaw et al. (2016), which proposed a study with 20 winter wheat varieties and five nitrogen fertilization treatments. The regression analysis of residues between yield and protein showed that the protein was statistically different for the determination of grain protein concentration, which was not limited by total N available during the season (Goos et al., 1982). Therefore, N rates applied in our experiment were enough to maximize yield because the majority of the measured protein concentration values were >11.5%. However, yield and protein are often negatively correlated (Fettel et al., 2012; Lollato and Edwards, 2015; Lollato et al., 2019). Likewise, we observed that the variety Everest obtained higher protein but lower yield when compared with WB Grainsfield. Nonetheless, our analysis suggest that Everest naturally has a higher protein concentration than WB Grainsfield, as determined by the residual analysis (Latshaw et al., 2016). Similar results were reported by variety performance trials in which grain protein concentration was measured, conducted in the neighboring state of Oklahoma (i.e., Everest was positioned in the highest testing protein group in 3 out of 12 trials, whereas WB Grainsfield was never ranked in the highest protein group) (Marburger et al., 2016).

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CONCLUSION

This study offers insights in managing wheat variety selection and its interaction with seed cleaning and seed treatment when seed is sourced from a growing season with high head scab incidence. The seed cleaning process increased stand establishment, suggesting that larger seeds were more vigorous in emerging from sowing, perhaps due to lower levels of infection with F. graminearum. Likewise, seed cleaning increased grain yield in the high-yielding variety WB Grainsfield, which could be attributed to its moderate susceptibility to head scab and to the cleaning method removing many damaged seeds. The variety SY Wolf, which is also moderately susceptible to scab but has a lower yield potential, did not increase yield in response to seed cleaning, perhaps suggesting that the response was dependent on yield level. Furthermore, fungicide seed treatment increased wheat yield across all varieties as compared with the control. Considering that seed treatment did not affect stand establishment, we hypothesize that this response could relate to (i) better seed vigor and improved tillering or (ii) to early season disease control after emergence (neither was measured in this experiment). Finally, grain protein concentration was inversely related to yield, and there were differences among varieties even when corrected for the same yield level. There was no significant effect of seed cleaning regime or fungicide seed treatment on protein concentration, and thus the differences likely reflected inherent varietal variation in protein content.

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REFERENCES


