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AGRONOMY & SOILS

Bronze Wilt Symptoms Reduced Yields in Georgia in 2024

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ABSTRACT

Bronze wilt was an issue for the cotton industry in the 1990s but mentions of bronze wilt in the literature were minimal until cotton leafroll dwarf virus (CLRDV) was observed across the cotton belt beginning in 2017. In 2024, bronze wilt symptoms were observed at high levels in Southwest Georgia. University of Georgia on-farm cotton variety trials (10 varieties evaluated across 19 locations) were used to quantify susceptibility to expression of bronze wilt symptoms and impacts on lint yield. Overall, the four varieties evaluated were determined to express bronze wilt symptoms; an additional variety outside the trial program was determined to be susceptible based on observations in grower fields. Differences in symptom severity were observed among locations, with some showing significant yield impacts, whereas others were unaffected. Averaged across non-yield-limiting locations (14 out of 19), 2 to 3% symptomatic plants were observed in symptomatic varieties: symptoms increased to 28 to 35% averaged across yield-limiting locations (5 out of 19). Where yield was affected, bronze wilt symptoms reduced lint yield 16 to 32% in the four susceptible varieties. Across all locations, a negative linear relationship was observed within susceptible varieties: a 1% increase in symptoms resulted in a 0.54% decrease in relative lint yield. These data are the first from replicated research to document yield losses associated with bronze wilt symptoms. Future research should evaluate in-field variety screening methods, genetics of susceptibility to expression of bronze wilt symptoms, and controlled environment experiments to replicate symptoms.

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In the mid- to late 1990s, bronze wilt became a major issue across cotton production regions of the U.S. Losses were reported in Louisiana beginning in 1995, whereas the remaining states in the Mid-South and the Southeast observed bronze wilt and noted losses through 1998 (Brown, 2000; Creech and Fieber, 2000; Gwathmey et al., 2001; Padgett et al., 2004; Phipps, 2000). Bronze wilt was described in the late 1990s as a plant malady for which the causal agent(s) were not universally agreed upon (Brown, 2000). Extension materials developed at that time classified stages of development and levels of severity into three groups: early or slight symptoms, mid-stage or moderate symptoms, and late stage or severe symptoms (Bell et al., 2000). Early or slight symptoms included bronzing of leaves, wilting, and higher leaf temperature in the upper canopy than in non-symptomatic plants. These symptoms could disappear, or they could progress. Mid-stage or moderate symptoms included the previously mentioned symptoms, plus reddening of the stem and abnormal shedding of fruit. Like early or slight symptoms, mid-stage or moderate symptoms might disappear, and leaf color might return to normal after fruit shed. Late stage or severe symptoms include all previously mentioned symptoms, plus necrosis of stem tissue or whole plants (Bell et al., 2000).

Much work was conducted on bronze wilt in the late 1990s and early 2000s, but no causal agent was ever associated with this disorder. McGraw (2000) stated there could be a connection to *Agrobacterium tumefaciens* (Smith and Townsend 1907) Conn 1942. Other *Agrobacterium* spp. were evaluated, but attempts to confirm this association failed (Nichols, 2001). Nitrogen and potassium fertility were evaluated to determine if plant nutrition affects bronze wilt (Gwathmey et al., 2001). No significant impacts of N and K fertility or tillage were observed on the incidence of bronze wilt. Hence, these practices could not be used to manage bronze wilt. Although a causal pathogen was not identified, it became clear through evaluation of small-plot variety trials at various institutions that some varieties were more susceptible to bronze wilt than others (Creech and Fieber, 2000; Phipps, 2000). Although certain varieties showed higher frequency of symptomatic plants, other varieties appeared to be unaffected, indicating that certain varieties were not susceptible to bronze wilt. Further, these small-plot variety trials showed little or no correlation between symptom expression and reduced yields. From research aimed at identifying the genetic background of susceptible varieties, it was noted that those sharing parentage with Tamcot SP-37 (PVP07200046; Bird, 1976) were more prone to developing symptoms (McGraw, 2000). However, other studies found no definitive link between specific parent lines and susceptibility to bronze wilt (El-Zik and Thaxton, 2001). Overall, the only management option for growers was to avoid planting susceptible varieties (Jenkins, 2002). Since the early 2000s, reports of bronze wilt in cotton have, until recently, been largely absent.

In 2017, cotton in Alabama displayed symptoms associated with cotton leafroll dwarf virus (CLRDV). Tests confirmed the presence of the virus, and since then this virus has been identified in every major cotton producing state from Arizona to Virginia (Aboughanem-Sabanadzovic et al., 2019; Alabi et al., 2020; Ali and Mokhtari, 2020; Ali et al., 2020; Avelar et al., 2019; Edula et al., 2023; Faske et al., 2020; Ferguson and Ali, 2022; Iriarte et al., 2020; Olmedo-Velarde et al., 2025; Price et al., 2020; Tabassum et al., 2019; Thiessen et al., 2020; Wang et al., 2020). Symptoms not associated with bronze wilt were also observed, but the overlapping symptoms raise the intriguing possibility of a relationship between bronze wilt and CLRDV (Conner et al., 2021; Edula et al., 2023; Parkash et al., 2021). Parkash et al. (2021) discussed the similarities between bronze wilt and symptoms associated with CLRDV and also raised the possibility of a relationship between the two. As no causal pathogen was ever identified for bronze wilt, it is impossible to determine whether the symptomatic plants observed in the 1990s were infected with CLRDV. However, the high degree of divergence among CLRDV isolates collected from different regions of the U.S., particularly in the sequence diversity of the Open Reading Frame (ORF) 0 gene (Adegbola et al., 2024; Ramos-Sobrinho et al. 2021), strongly suggests that this virus has been present in the U.S. cotton belt for a considerable time. It is therefore plausible that the emergence of bronze wilt could have coincided with the initial introduction of CLRDV into the U.S. As with bronze wilt, CLRDV exhibits a distinct varietal response. In both bronze wilt and CLRDV some varieties consistently show a higher frequency of symptomatic plants, whereas others appear largely unaffected (Parkash et al., 2021). Despite these observations, neither bronze wilt nor CLRDV has been conclusively linked to yield losses in replicated yield trials conducted on a commercial scale.

In 2024, Southwest Georgia observed what was likely the most severe outbreak of bronze wilt-like symptoms since the late 1990s. Severe symptoms were observed in five commercially available varieties, three of which were known to show these types of symptoms from 2020 to present but continued to be planted due to high yield potential. Since 2010, University of Georgia has conducted an on-farm variety evaluation program (Collins et al., 2011). This program allows multiple varieties to be evaluated across a wide range of environments to determine yield stability, and this program continued in 2024. This offered the opportunity to collect data across a wide range of geography, which was insightful due to the variability in bronze wilt symptom incidence across locations. However, there was clearly a variety effect, with four of the evaluated varieties displaying symptoms. The objective of this research was to use these on-farm variety trials to determine variety susceptibility to bronze wilt and the impact of variety on cotton yield in response to bronze wilt symptoms. It is important to note that throughout this paper, the term bronze wilt is used to describe symptoms similar to what was observed in the late 1990s. In 2024, these symptoms appear to be associated with CLRDV, but much more work has to be done to state definitively that CLRDV is the causal agent of these symptoms. It is not possible to conclude if the bronze wilt symptoms observed in 2024 result from the same cause as the bronze wilt symptoms present in the late 1990s.

MATERIALS AND METHODS

On-farm variety trials were conducted in 19 locations across the cotton producing region of Georgia in 2024. Table 1 provides the county in which each trial was conducted, along with planting, defoliation, and harvest dates. Varieties evaluated in 2024 are listed in Table 2. Varieties were planted in large plots, ranging from 5 to 11 m wide, and 90 to 350 m long. Treatments were arranged in a randomized complete block design with three replications in each

Table 1. Location information for the 2024 UGA Cotton On-Farm Variety Evaluation Program

County	Irrigation	Planting Date	Defoliation Date	Harvest Date
Brooks	Yes	31 May	31 Oct	23 Nov
Burke	Yes	31 May	09 Oct	31 Oct
Burke	No	23 May	01 Oct	01 Nov
Colquitt	No	31 May	28 Oct	12 Nov
Colquitt	Yes	07 June	04 Nov	18 Nov
Cook	Yes	30 April	22 Oct	12 Nov
Dooly	Yes	02 May	21 Oct	05 Nov
Grady	No	22 May	09 Oct	31 Oct
Houston	Yes	23 May	14 Oct	05 Nov
Jeff Davis	Yes	29 May	01 Nov	05 Dec
Jenkins	Yes	26 May	01 Nov	23 Nov
Mitchell	No	03 May	21 Oct	12 Nov
Mitchell	Yes	03 June	16 Oct	02 Dec
Oconee	No	22 May	11 Oct	05 Nov
Pulaski	Yes	30 May	25 Oct	06 Dec
Sumter	Yes	05 June	01 Nov	25 Nov
Tattnall	No	21 May	28 Oct	16 Nov
Turner	Yes	07 June	21 Oct	03 Dec
Worth	Yes	28 May	08 Oct	28 Oct

Table 2. Varieties Evaluated in the 2024 UGA Cotton On-Farm Variety Evaluation Program

Variety	Manufacturer
DP 2038 B3XF	Bayer CropScience, 800 N. Lindbergh Blvd., St. Louis, MO
DP 2127 B3XF	
DP 2333 B3XF	
ST 6000 AXTP	BASF Corp., 26 Davis Dr. Research Triangle Park, NC
NG 5430 B3XF	Americot Inc., 5013 122nd St., Lubbock, TX
DG 3615 B3XF	Nutrien Ag Solutions, 3005 Rocky Mountain Ave., Loveland, CO
DG 3799 B3XF	
DG H959 B3XF	
AR 9371 B3XF	Land O' Lakes Inc., 4001 Lexington Ave. N., Arden Hills, MN

location. Cotton was planted and managed throughout the season with grower cooperator practices and equipment, with assistance provided by the local county extension agent.

Upon onset of bronze wilt symptoms (late July, early August 2024), county extension agents measured 30.5 m of row and counted symptomatic and asymptomatic plants within each plot at a single point in time for each location. These data were converted to a percentage of symptomatic plants prior to statistical analysis. Symptoms evaluated are described in depth by Bell et al. (2000) and Parkash et al. (2021) and included bronzing/reddening of leaves, wilted plants, reddened stems/petioles, leaves that were warm to the touch (above ambient temperature), untimely fruit shed, plant death, and combinations of these symptoms. Examples of symptomatic plants can be found in Figs. 1 through 5. At harvest, commercially available cotton pickers were used to harvest each plot, and seed cotton weights for each plot were determined by a boll buggy equipped with a load cell scale system or a large platform scale in the field. Samples were collected from a single replicate from each trial and transported to the UGA MicroGin in Tifton, GA to obtain a lint percentage for each variety in each location (Li et al., 2011).

All data were subjected to ANOVA using PROC GLM in SAS Enterprise Guide version 8.3 (SAS Institute, Cary, NC) to determine the impacts of location and variety on severity of bronze wilt and lint yield. Variety-by-location interactions were evaluated prior to analysis and were significant ($p <$ 0.0001). Thus, data were separated into two groups: locations where yield was limited by bronze wilt (Brooks [irrigated], Mitchell [irrigated and dryland], and Colquitt [irrigated and dryland] counties), and

Figure 1. Typical bronze wilt symptoms observed in Georgia, displaying reddened stems and petioles, and wilted plants at the second week of squaring. Picture taken in DG 3799 B3XF by Ashley Smith, in Coffee County, GA.

Figure 2. Symptomatic plant displaying untimely fruit shed. Leaves present on the left, leaves removed on the right. Picture taken of DG 3799 B3XF just prior to flowering by Jeremy Kichler, in Colquitt County, GA.

Figure 3. Pre-bloom symptomatic plants. Pictured are normal plants within symptomatic varieties, wilted plants, and dead plants. Varieties pictured are NG 5430 B3XF (left) and DG H959 B3XF (right). Pictures taken in Colquitt County, GA by Jeremy Kichler.

Figure 4. Example of symptom onset during flowering. Picture taken of PHY 475 W3FE in Colquitt County, GA by Jeremy Kichler.

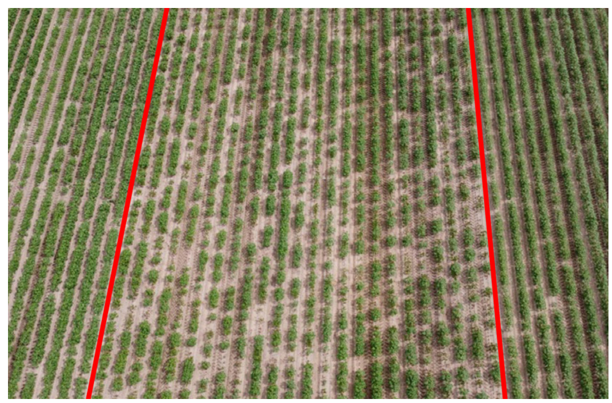

Figure 5. Aerial photo taken of pre-bloom symptoms in the location with highest level of symptoms (Colquitt County, GA Irrigated). Four symptomatic varieties between the two red lines, and asymptomatic varieties outside of the red lines.

locations where yield was not limited by bronze wilt (remaining 14 locations). Percentage symptomatic plants and lint yield were response variables evaluated by variety, where replicate and location (within each group) were considered random factors. Means were separated using a Fisher's Protected LSD where $\alpha = 0.10$ due to the variability noted in on-farm research. Further, once it was determined which varieties are more likely to display bronze wilt symptoms, regression analysis was used to investigate lint yield in response to percentage of plants showing bronze wilt symptoms. To normalize data, lint yield of the four symptomatic varieties was converted to a percentage of the location lint yield average (including all 10 varieties) for all locations prior to regression, where relative lint yield was the dependent variable, and the percentage of symptomatic plants was the independent variable. Regression analysis was also conducted in SAS, and all graphs were constructed in SigmaPlot version 15.0 (Systat Software, San Jose, CA).

RESULTS AND DISCUSSION

In 2024, bronze wilt-like symptoms could be found across the state of Georgia. However, there was a distinct geographical effect: severity was higher west of Interstate 75 and south of US Highway 82. Historically, this geographic area accounts for approximately 35% of cotton hectarage in Georgia (Daniel, 2025). Bronze wilt symptoms were not uniformly present within this area, even for susceptible varieties, and reports of severe symptomatic fields north of the mentioned area also occurred. These factors made it extremely difficult to examine correlations between planting date or environmental conditions with symptom onset. To date, it appears that variety is the main factor affecting expression of bronze wilt symptoms, whereas other factors influencing symptomatology remain unknown.

The only varieties evaluated that expressed bronze wilt symptoms were DG 3615 B3XF, DG 3799 B3XF, DG H959 B3XF, and NG 5430 B3XF (Figs. 6 and 7). Averaged across locations with low incidence of bronze wilt, 2 to 3% of these plants showed bronze wilt symptoms, yet no symptoms were observed in the other varieties evaluated in the on-farm trial (Fig. 6). It is important to note that the highest level of symptoms observed in these locations was 17.7%; however, yield was not reduced in this instance, classifying it as a low incidence location (data not shown).

Averaged across locations with high bronze wilt incidence, symptom incidence was significantly higher for the four susceptible varieties, ranging from 28 to 35% (Fig. 7). These locations were clearly more severe than the aforementioned locations, where up to 55% symptomatic plants were observed (data not shown). Regardless of location, DG 3615 B3XF, DG 3799 B3XF, DG H959 B3XF, and NG 5430 B3XF are varieties that are more prone to display bronze wilt symptoms out of the 10 varieties evaluated in this trial program. Additional observations were reported concerning symptom expression in PHY 475 W3FE, with up to 35 to 40% symptomatic plants observed in severe situations. This would place PHY 475 W3FE in the same group as the four susceptible varieties that were evaluated in the 2024 on-farm variety trial program. Based on these results, the bronze wilt symptoms observed in Georgia in 2024 are strongly influenced by variety, which is consistent with bronze wilt reported in the late 1990s (Brown, 2000; Creech and Fieber, 2000; El-Zik and Thaxton,

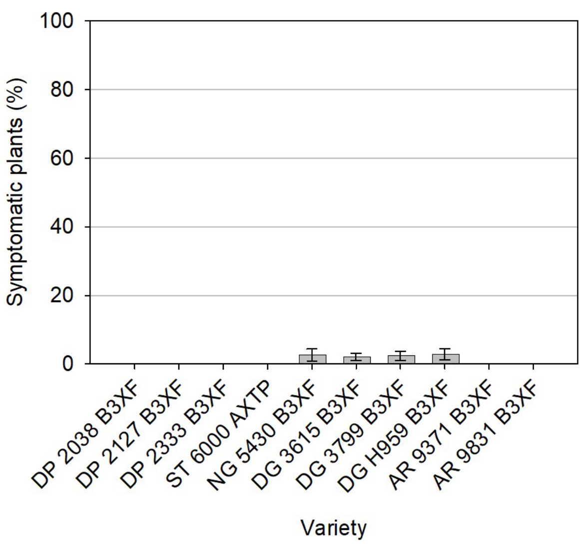

Figure 6. Bronze wilt symptoms in non-yield limiting locations (14 of 19 total locations). Data are averaged across location. Symptomatic plants are expressed as a percentage of the total number of plants evaluated in each plot of each variety, which was quantified at the end of July or early August. Bars represent the mean ± standard error.

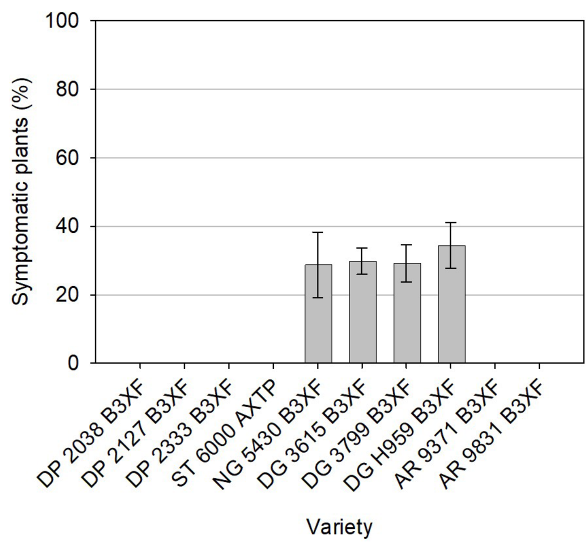

Figure 7. Bronze wilt symptoms in yield limiting locations (5 of 19 total locations). Data are averaged across location. Symptomatic plants are expressed as a percentage of the total number of plants evaluated in each plot of each variety, which was quantified at the end of July or early August. Bars represent the mean ± standard error.

2001; Gwathmey et al., 2001; Padgett et al., 2004; Phipps, 2000,).

Averaged across locations where bronze wilt incidence was low, NG 5430 B3XF, DG 3799 B3XF, DP 2333 B3XF, DP 2038 B3XF, DG 3615 B3XF, DP 2127 B3XF, and ST 6000 AXTP were the highest yielding varieties (1,480 to 1,533 kg ha^{-1}) compared to DG H959 B3XF (1,392 kg ha^{-1}) (Fig. 8). At these trial locations, multiple highly symptomatic varieties (NG 5430 B3XF, DG 3799 B3XF, and DG 3615 B3XF) were top yielding varieties. Thus, yield was not limited by presence of bronze wilt symptoms in these locations. These results are similar to previous variety trial results, where DG 3799 B3XF and DG 3615 B3XF have performed exceptionally well in the Lower Southeast and where incidence of bronze wilt symptoms have remained low (Hand et al., 2022; 2023a, b; 2024).

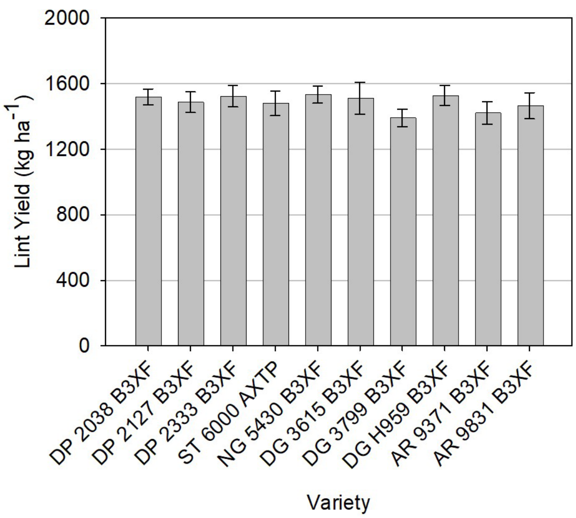

Figure 8. Lint yield of 10 varieties evaluated where bronze wilt symptoms were not yield limiting (14 of 19 total locations). Data are averaged across location. Bars represent the mean ± standard error.

Averaged across highly symptomatic and yield-limiting trial locations, there was a clear division between the four symptomatic and the six non-symptomatic varieties with respect to lint yield (Fig. 9). The four symptomatic varieties (DG 3615 B3XF, DG 3799 B3XF, DG H959 B3XF, and NG 5430 B3XF) had a 200 to 450 kg ha^{-1} yield reduction as compared to the six asymptomatic varieties that were evaluated. When averaged across these locations, a 16 to 32% yield loss occurred in symptomatic versus asymptomatic varieties. In the most severely impacted location, Colquitt irrigated, an incidence of 55% symptomatic plants was observed, and the corresponding yield losses were nearly 40% as compared to asymptomatic varieties (data not shown).

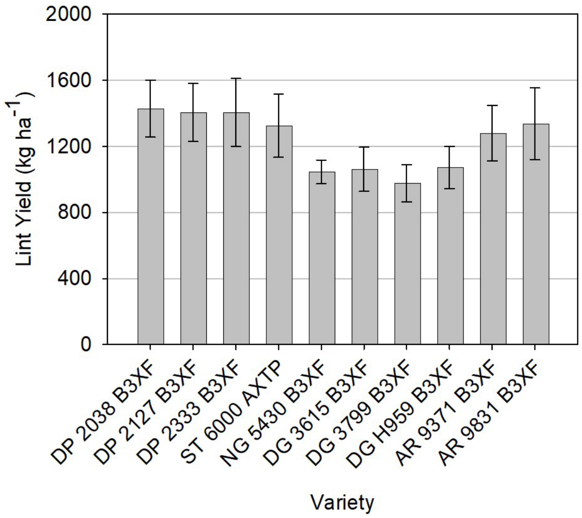

Figure 9. Lint yield of 10 varieties evaluated where bronze wilt symptoms were yield limiting (5 of 19 total locations). Data are averaged across location. Bars represent the mean ± standard error.

Historically, the expression of bronze wilt symptoms has been associated with some sort of stress, whether it be biotic or abiotic (El-Zik and Thaxton, 2001; Padgett et al., 2004). However, in this study, the trial in which the highest incidence of symptomatic plants was observed was planted in an intensely managed field with no apparent stress prior to onset of bronze wilt symptoms. Thus, the hypothesis that bronze wilt symptoms are induced in susceptible varieties solely by abiotic stressors requires further evaluation. In the late 1990s, variety susceptibility to bronze wilt and the associated lint yield was assessed in many trials. In many of these cases, varieties visually rated as susceptible to bronze wilt were also among the highest yielding varieties (Creech and Fieber, 2000; Phipps, 2000). Additionally, where these symptoms have been observed in association with CLRDV, yield losses on a per plant basis have been reported, but yield losses on a land area basis have not been reported in replicated trial data (Mahas et al., 2022; Parkash et al., 2021). The results presented herein are the first to demonstrate yield losses on a land area basis associated with bronze wilt symptoms in replicated research trials.

To normalize yield responses across locations for the four symptomatic varieties, relative yields were calculated as a percentage of the lint yield average for each location prior to regression analysis.

Overall, for the four varieties exhibiting bronze wilt symptoms, there was a significant, negative-linear relationship between the percentage of symptomatic plants and lint yield ($p < 0.0001$). Across locations within symptomatic varieties, for every percentage increase in symptomatic plants, relative lint yield was reduced 0.54% (Fig. 10). This demonstrates the severity of yield loss when symptoms occur.

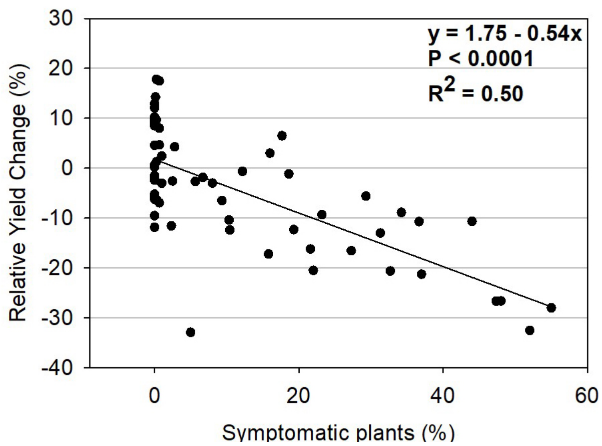

Figure 10. Relative yield change (expressed as a percent of the overall location average) of the four symptomatic varieties evaluated (NG 5430 B3XF, DG 3615 B3XF, DG 3799 B3XF, and DG H959 B3XF) in response to the number of symptomatic plants observed.

CONCLUSIONS

In 2024, bronze wilt symptoms significantly impacted Georgia cotton production and the cotton industry as a whole. Five varieties were identified that were more likely to display bronze wilt symptoms (DG 3615 B3XF, DG 3799 B3XF, DG H959 B3XF, NG 5430 B3XF, and PHY 475 W3FE) than other varieties. This is not to say that other varieties will not display bronze wilt symptoms, but these five varieties have a greater propensity to do so. This research is the first to document yield losses due to bronze wilt symptoms in replicated trial work and at an on-farm level. Although correlations with planting date and environmental conditions could not be established, increases in the percentage of symptomatic plants had a significant negative impact on lint yield for symptomatic varieties.

To the authors' knowledge, no significant impacts of bronze wilt were reported outside of the state of Georgia in 2024. Still, these data from Georgia are important. Based on the data presented, bronze wilt is strongly associated with cotton genetics and breeding. Jenkins (2002) stated that the control for bronze wilt was known, and that control method was to avoid planting varieties that carry the susceptibility gene(s). Thus, it has long been widely recognized that the best way to avoid bronze wilt is to avoid planting varieties that are known to show symptoms. However, bronze wilt has not been a Beltwide issue since the 1990s. There are still academic and industry scientists that experienced bronze wilt in the 1990s and continue to work in the cotton industry today. However, many of these experts are retired or nearing retirement, which means the knowledge and expertise on this issue is fading from the industry. The industry should be concerned about this issue, and people entering the cotton industry should be trained to identify bronze wilt symptoms, particularly in a breeding and genetics situation whether that be public or private.

Although three of the varieties evaluated in this study demonstrated bronze wilt symptoms in recent years (DG 3615 B3XF, DG 3799 B3XF, and DG H959 B3XF), what was most alarming in 2024 was the two new varieties that displayed bronze wilt symptoms (NG 5430 B3XF and PHY 475 W3FE). This is especially concerning because each of the companies producing these varieties operates independent breeding programs, and it is likely that certain parent lines within these breeding programs carry susceptibility gene(s) to expression of bronze wilt. Cruz et al. (2023) discussed the narrow genetic base of cotton cultivars in Brazil, stating that 12 out of 68 identified ancestors contributed more than 52% of genes in commercially available cultivars. They also addressed how such a narrow genetic base lends itself to a multitude of issues, including pest susceptibility. Because pedigrees of commercial cultivars are not disclosed in patent application, the genetic background of the five symptomatic varieties discussed herein remains unknown. This issue is further exacerbated because screening for susceptibility is neither reliable nor consistent across years and geographical locations. As a result, a major concern for the cotton industry is the potential release of other commercial varieties that share similar parentage with these five varieties, raising the possibility that the outbreak observed in Georgia in 2024 could be repeated in other regions in the future.

There are multiple areas in which future research should be conducted. First, a reliable method for high-throughput in-field variety screening should be tested and used to identify varieties that show bronze wilt symptoms prior to reaching the market. This way a propensity for expression of bronze wilt could be identified prior to planting. Second, genetic markers associated with bronze wilt symptoms should be identified and used by private and public breeding programs to select for resistant cultivars. This has been ongoing, as BASF Corporation has identified markers associated with bronze wilt and patents have been filed in association with the technology. Lastly, controlled-environment experiments should be conducted to investigate the connection between CLRDV and bronze wilt symptoms. A key challenge in studying this issue is that this has been the first major outbreak of bronze wilt symptoms since the late 1990s. Thus, replicating symptoms in controlled environments is crucial. Much of this work is ongoing at the University of Georgia, largely supported by checkoff dollars, with plans to allocate more time and resources to this issue in the coming years to better understand and address this complex issue.

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