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Genetic resistance to and effect of leaf rust and powdery mildew on yield and its components in 50 soft red winter wheat cultivars

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ABSTRACT

Effects of leaf rust (caused by *Puccinia triticina* f. sp. *tritici* Eriks.) and powdery mildew [caused by *Blumeria graminis* (DC.) E. O. Speer f. sp. *tritici* Em. Marchal], on performance of 50 soft red winter (SRW) wheat (*Triticum aestivum* L) cultivars were evaluated under natural field conditions. Widely grown cultivars released from 1919 to 2009 with varying disease resistance were grown in split-plot experiments in 2010 and 2011. Treated replications received seed treatments of triadimenol, captan and imidacloprid and foliar applications of propiconazole and prothioconazole + tebucanazole fungicides. Non-treated replications received only tebucanazole + metalaxyl + imazalil seed treatments. Final mean disease severity, agronomic, yield-related traits, yield components and spike characteristics were analyzed to determine individual and combined effects of leaf rust and powdery mildew on the cultivars. Yield losses as high as 54% were observed in the susceptible cultivar Red May. Average yield losses ranged from 1% to 21%. Yield losses primarily due to powdery mildew were as high as 14%, and losses primarily due to leaf rust were as high as 33%. Powdery mildew had the largest negative correlation with harvest index and seeds/spike. Leaf rust was most negatively correlated with plant biomass and harvest index, with a less consistent negative relationship with kernel weight.

1. Introduction

Identifying and maintaining genetic resistance to diseases in cultivars has been a central focus of wheat breeding research since the beginning of organized cultivar development programs. In the mid-Atlantic and southeastern regions of the USA, the two primary diseases of soft red winter (SRW) wheat are leaf rust and powdery mildew. While the impact of these diseases on grain yield has been documented, their impact on yield components in common wheat is less clearly understood.

Battling the rusts of wheat has been a central campaign of breeding and pathology for several hundred years, with significant progress being made in the 20th century (McIntosh et al., 1995). Leaf rust is the most widespread of the three rusts and is prevalent nearly everywhere wheat is grown (Kolmer, 1996). In a survey of incidence and severity of leaf rust in all wheat-producing states of the USA from 1918 to 1976, Roelfs (1978) reported estimated yield losses due to leaf rust in nearly every state surveyed, with statewide losses as high as 50% in one instance. In the southeastern USA, leaf rust can reach epidemic levels during years that favor pathogen development (Long et al., 1985; Roelfs, 1986; Subba Rao et al., 1990). In a study conducted in Mississippi, a model was developed that estimated wheat yield losses as high as 1% for each 1% increase in disease severity at the milky ripe stage (Khan et al., 1997). Leaf rust has been reported to impact yield in several ways. Herrera-Foessel et al. (2006) reported a reduction in kernels/m^2 as the primary effect of leaf rust on yield. Many authors have reported reduction in kernel weight as a primary effect of leaf rust infection (Chester, 1946; Keed and White, 1972; Salazar Huerta et al., 1993; Sayre et al., 1998; Singh and Huerta-Espino, 1994). Additionally, Singh and Huerta-Espino (1994) reported yield losses resulting from leaf rust due to decreased biomass, kernels/spike, test weight, and harvest index. Use of fungicides is often neither economical nor feasible in many production systems; so development of cultivars with durable resistance is the most economical and therefore the

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preferred method for combating leaf rust (Kolmer, 1996). Control of leaf rust using resistant cultivars has been quite successful in the northern USA and Canada; but in the southern regions of the USA, single gene resistance to prevailing races is often lost in a few years (Kolmer, 1996). It is thought that this is primarily due to the diverse virulence in the pathogen population, because of proximity to overwintering and over-summering areas of the fungus (Khan et al., 1997).

Powdery mildew is frequently the most important disease of wheat in maritime and semi-continental environments (Bennett, 1984). It has been reported to reduce wheat yields by as much as 45% (Fried et al., 1981; Leath and Bowen, 1989; Stromberg et al., 1990). In studies with strictly natural inoculum sources, yield has been reduced by an estimated 10%–15% (Frank and Ayers, 1986; Lipps and Madden, 1989b). Yield losses have been explained by a reduction in tiller numbers and seeds/spike; however, these effects differed by environment (Bowen et al., 1991). Effects of powdery mildew on wheat quality have also been reported but were not consistent across environments (Everts et al., 2001).

Leaf rust and powdery mildew have a negative and additive effect on yield when both pathogens incite disease epidemics (Bowen et al., 1991). As with leaf rust, resistant cultivars are often the most economical and efficient means of controlling powdery mildew (Griffey and Das, 1994). While adult plant resistance has been identified, mapped and characterized as being durable, hypersensitive race-specific resistance genes continue to be used widely in breeding programs. The latter type of resistance generally is not durable due to a rapid buildup of isolates in *Blumeria graminis* populations with matching virulence genes (Griffey and Das, 1994). Very useful information can be obtained from studies conducted in controlled environments, but studies with natural inoculum sources in field trials are needed as they are more similar to conditions under commercial production and are, therefore, important to breeding efforts. However, in order to draw definitive conclusions about the effects of disease on yield loss, comparisons of performance between healthy non-infected plots with those having varying levels of disease infection are required (James and Teng, 1979), as was achieved in the current study. The utilization of historically significant cultivars which have been widely grown and studied extensively also contributed to the uniqueness of the current study.

The objectives of this study were to examine the impact of cultivar resistance on powdery mildew and leaf rust, and the effect of these two diseases on yield, agronomic traits, spike characteristics and yield components in 50 historically significant SRW wheat cultivars.

2. Materials and methods

2.1. Experimental

Field experiments were conducted at the Eastern Virginia Agricultural Research and Extension Center near Warsaw, VA (Kempsville loam, 37° 59′ N, 76° 46′ W, 40.5 m elevation) during the 2009–10 and 2010–11 growing seasons and at the Tidewater Agricultural Research and Extension Center near Holland, VA (Eunola loamy fine sand, 36° 68' N, 76° 77' W, 18.9 m elevation) during the 2010–2011 growing season. The experiments each included 49 soft red winter (SRW) wheat cultivars released from 1950 to 2009 (Table 1) and one historical cultivar, Red May, released in 1919. The cultivars represent a sample of the most historically significant cultivars grown in Virginia and the mid-Atlantic region during the period, according to the seed certification records of the Virginia Crop Improvement Association (David Whitt, personal communication, 2009). Replicated plots were planted on 23 October 2009 and 17 October 2010 at Warsaw and on 2 November 2010 at Holland. Each experimental unit consisted of a seven-row yield plot, 2.7 m in length with 15.2 cm (Warsaw) or 17.8 cm (Holland) spacing between rows. The harvested plot area was 2.9 m^2 (Warsaw), and 3.4 m^2 (Holland). Plots were seeded at a density of 520 seeds/m^2 based on kernel weight of the seed source.

The study was planted as a split-plot design, with disease control being the whole plot factor and cultivar being the sub-plot factor. For the disease controlled (treated) plots, seeds were treated with Baytan® fungicide (triadimenol, Bayer Crop Science) at a rate of 14.1 g active ingredient (a.i.)/45.4 kg, Captan 400® fungicide (Captan, Bayer Crop Science) at a rate of 28.4 g a.i./45.4 kg, and Gaucho® XT insecticide (Imidacloprid, Bayer Crop Science) at a rate of 16.5 g a.i./45.4 kg to control seedling pests and diseases. For the plots not controlled for foliar disease (untreated plots), Raxil-MD® Extra (Tebuconazole, Metalaxyl and Imazalil, Bayer Crop Science) at a label rate of 5 fluid ounces per hundred pounds, for 0.7 g, a.i./45.4 kg, 0.9 g a.i./45.4 kg, and 1.6 g a.i./45.4 kg for each active ingredient respectively, was used as the seed treatment to control seed-borne diseases and to maximize seed germination and emergence.

Fall nutrient management and spring nitrogen (N) applications were based on standard local management practices (Brann et al., 2000) and recommendations from the Virginia Cooperative Extension Soil Testing Laboratory. All plots were treated with growth regulator (Trinexapac-ethyl) between growth stage (GS) 25 and GS 30 (Zadoks et al., 1974) at a rate of 104.8 g a.i./ha to minimize lodging. Weed control was achieved using herbicide Finesse (DuPont) at Warsaw in 2010 and Harmony-Extra SG (DuPont) at all locations in 2011 at rates recommended by Virginia Cooperative Extension (Hagood and Herbert, 2011).

Fungicide treated plots received Tilt® (Propiconazole, Syngenta) between GS 31 and GS 45 to control foliar diseases, primarily powdery mildew. Plots at Warsaw in 2010 were treated at a rate of 58.5 g a.i./ha on April 2 and April 15. In 2011, plots were treated at a rate of 117 g a.i./ha on April 14 (Warsaw) and April 21 (Holland). Prosaro® (Prothioconazole, Tebuconazole, Bayer Crop Science) was applied at GS 50 (spike emergence) to control leaf rust and fusarium head blight (*Fusarium graminearum* Schwabe). All treated plots during both years were treated at a rate of 212.8 g a.i./ha. Foliar fungicide was not applied to the untreated plots. Late season leaf rust and powdery mildew were observed at very low incidence and severity in only a few plots in the treated portions of the study.

2.2. Disease ratings and plant trait assessments

Both diseases were present from naturally occurring inocula. Rating of disease reaction was initiated when sufficient levels of infection developed on known highly susceptible cultivars used in the study. Powdery mildew was rated three times at Warsaw in 2010, (March 31, April 20 and May 5) and three times in 2011, (April 12, April 26 and May 11). These ratings were conducted at flag leaf emergence (Zadoks 40), after head emergence (Zadoks 59), and during grain-fill (Zadoks 70–80). Powdery mildew ratings were initiated when sufficient levels of infection were present (3–5 rating) on the cultivars Blueboy, Tribute, and Seneca. Lower levels of powdery mildew incidence and severity occurred at Holland and plots were rated only once on May 16 when infection levels were at a maximum. Powdery mildew ratings were based on a sample of representative plants throughout the plot, which were rated for leaf coverage on a 0 to 9 scale (0 = no disease to 9 = severe infection) in a manner similar to Saari and Prescott (1975). Final disease ratings were used to calculate potential loss estimates, because these ratings were made at the most critical stage for yield loss (Lipps and Madden, 1989a, 1989b) and when the disease was at maximum