GERmplasm

Registration of Spring Wheat Germplasm
ND 756 Combining Resistances to Foliar Diseases and Fusarium Head Blight

ABSTRACT
ND 756 hard red spring wheat (HRSW) (Triticum aestivum L.) (Reg. No. GP-837, PI 648034) was developed at North Dakota State University and released by the North Dakota Agricultural Experiment Station (NDAES). ND 756 was released mainly for its high level of resistance to SNB, STB, and tan spot. ND 756 is also resistant to the prevalent races of stem rust and leaf rust found in the northern Great Plains of the U.S. ND 756 is moderately resistant to FHB and has good agronomic performance but does not meet the high grain quality requirements to qualify for release by NDAES.

Methods
Early Generation Development
ND 776 was developed using a modified bulk breeding procedure. The F₁ generation of the cross resulting in ND 756 was planted in the greenhouse in the spring of 1998, and the F₂ population was grown in the field at the NDSU experiment station, Prosper, ND in the summer of 1998. Two hundred selected spikes from the F₂ population were threshed separately and advanced to the F₃ generation using the single seed descent method. In the summer of 2000, spikes from each of the 200 F₃ plants were included...
in preliminary yield trials (PYT). Subsequently, based on yield and other agronomic performances, selected plots from PYT were harvested in bulk as F_{4.5} and included in advanced yield trials (AYT) in the summer of 2001. Ten selected spikes from each of the F_{4.5}, AYT plots were threshed individually and sent to Christchurch, New Zealand in an off-season nursery in the winter-spring of 2001–2002 to be sown as F_{5.5} lines in 1.2 m head rows. The selected row plots were harvested in bulk and entered in the ND HRSW variety trials (HRSW-VT) in the summers of 2002 and 2003. Selection in F_{1} and F_{2} generations were based on good agronomic appearance and resistance to FHB and foliar diseases. In addition to the later traits, selection in PYT and AYT included yield and its components; and a few quality traits, such as grain volume weight and grain protein content. In New Zealand, plots were selected visually based on agronomic traits and grain shattering.

**Line Evaluation**

ND 756 was tested for its reaction to different races of tan spot, leaf and stem rusts, SNB, STB, and FHB in the greenhouse and in the field during the period of 2001 to 2006. The SNB, STB and tan spot are the major components of the leaf spotting disease complex of wheat in North America. A complex of these diseases occurs in nature. Hence managing leaf spot is difficult; however, resistant cultivars are the most effective and economical means of controlling leaf spot.

Tan spot of wheat can cause two phenotypically distinct and independent symptoms: tan necrosis and extensive chlorosis (Lamari and Bernier, 1989). Currently, eight races of tan spot have been identified (Lamari et al., 2003). From 2004 to 2006, ND 756 was tested for resistance to four races of tan spot across six trials in the greenhouse. The races tested included all the virulent races observed in North America, i.e., race 1, the most prevalent tan spot race in ND, and the races 2, 3, and 5. The greenhouse trails were arranged in a randomized complete design (RCBD) with three replicates and three plants per replicates as the experiment unit. Using the same experiments, ND 756 was also tested against _P. tritici-repentis_ toxins P trxA and P trxB, two of the three host-specific toxins of tan spot that have been reported to date (Lamari et al., 2003). The 1–5 lesion type scale developed by Lamari and Bernier (1989) where 1 is resistant with small, dark brown to black spots without any surrounding chlorosis or tan necrosis, and 5 is susceptible with dark brown or black centers which may or may not be distinguishable (most lesions consist of coalescing chlorotic or tan necrotic zones), was used to evaluate ND 756’s resistance to tan spot races.

ND756 was evaluated for reaction to SNB based on a 1–5 lesion type scale developed by Feng et al. (2004), where 1 = pinpoint dark brown lesions without chlorosis; 2 = small lesions with very little necrosis or chlorosis; 3 = chlorotic or necrotic lesions completely surrounded by a chlorotic ring; 4 = lesions completely surrounded by chlorotic zones, some of the lesions coalescing; and 5 = extensive chlorosis and large necrotic lesions. Ratings of 1–2 are considered as resistant while those with 3–5 are classified susceptible. ND 756 was also evaluated to STB based on a 0–5 scale developed by McCartney et al. (2002), where 0 is immune, 1 highly resistant, 2 resistant, 3 moderately susceptible, 4 susceptible, and 5 highly susceptible. Ratings of 0–2 are considered as resistant while those with 3–5 are considered susceptible.

The evaluation for ND 756 for SNB and STB was based on eight greenhouse experiments arranged in a RCBD with three replicates and three plants per replicate.

Screening of ND 756 for FHB however, was conducted from 2002 to 2004 in ten FHB nurseries under both field (six location-years) and greenhouse (four experiments) conditions. The field FHB nursery was laid out in a RCBD with four replicates and inoculated with FHB pathogen using “Spray inoculation” method (Rudd et al., 2001) and overhead mist irrigated to enhance disease development. The entries were assigned to a hill plot. Similarly, the greenhouse experiments were arranged in a RCBD with three replicates. The entries were assigned to a 0.5 m row plot.

The reaction type of ND 756 to the prevalent races of leaf and stem rusts was done on the basis of four field tests (RCBD, four replicates, and 1 m row-plot per replicate) and six greenhouse tests (RCBD, three replicates, and four plants per replicates) conditions from 2002 to 2004. In the greenhouse experiments ND 756 was specifically evaluated for resistance to the predominant stem rust pathotypes Pgt-QCCJ,-QTHJ,-QFCCQ,-RTQQ,-TPMK,-RHTS, and–HPHJ; and leaf rust pathotype THBL.

ND 756 was also evaluated for some agronomic and quality traits in the PYT in 2002; and in AYT during 2001. Subsequently, ND 756 was tested in the HRSW-VT in 2002 and 2003. Both PYT and AYT were arranged in a RCBD with two and four replicates, respectively. The experiment unit consisted of seven rows, three m long, and 30 cm apart. While the PYT was conducted at Caselton and Prosper, ND, the AYT was grown in two additional locations; Carrington and Minot, ND. The HRSW-VT is a state-wide trial conducted at seven locations across ND in a RCBD with four replicates. The plot size consisted of eight rows, ten m long, and 30 cm apart.

Kernel shattering of ND 756 was scored on HRSW-VT based on visual score method (Zhang and Mergoum, 2007) which consisted of assigning a score on a 1 to 5 scale three weeks after Feekes’ stage 11.4. The score is based on visual estimation of the percentage of shattered kernels from spikes (1 = 0%, 2 = 20%, 3 = 50%, 4 = 80%, 5 > 80%).

**Seed Purification and Increase**

ND 756 was produced from a bulk of one F_{5.5} head row selected in 2002 at the Christchurch, New Zealand off-season nursery. ND 756 was further purified by selecting 200 heads from the quality drill strips (F_{5.8}) at Prosper, ND in 2003. These spikes were threshed individually and seeded as head rows at Prosper in 2004. Non-uniform rows were discarded and the remaining rows were bulked.

**Statistical Analysis**

Statistical analyses of data were done using SAS (SAS Institute Inc., Cary, NC). Grain yield and other agronomic data such as grain volume weight from the AYT and HRSW-VT were subjected to analysis of variance across locations within years; a combined analysis across location-years was performed whenever error variances were homogeneous. The analysis of AYT and HRSW-VT included only entries common to the trials across all years. A mixed model with environments and genotypes as fixed factors and replications within environments as random factors was used for within-year analyses. Similarly, across-year analyses were also done according to a mixed model with genotypes and...
location-year combinations as fixed factors and replications within location-year combinations as random factors. Tukey’s HSD test ($\alpha = 0.05$) (Tukey, 1949) was used to compare the least squares means for the genotype effects.

**Characteristics**

**Agronomic and Botanical Description**

ND 756 is an awned, medium-early maturing and semi-dwarf hard spring wheat. It has a lax head type with plant height (92 cm), 5 cm shorter ($P < 0.05$) than ‘Parshall’ (PI 613587) and 7 and 5 cm taller than ‘Reeder’ (PI 613586) and ‘Alsen’ (PI 615543; Frohberg et al., 2006), respectively. The height of ND 756 is, however, similar to ‘Steele-ND’ (PI 634981; Mergoum et al., 2006a) and Steele-ND, two days earlier ($P < 0.05$) than ‘Howard’ (PI 642367; Mergoum et al., 2006b) and two days later than Parshall and Alsen. ND 756 is similar to Alsen for grain shattering (score 2), but more resistant ($P < 0.05$) to grain shattering compared to Sumai3 (score 4). ND 756 is medium resistant to lodging, similar to Alsen.

**Disease Reactions**

ND 756 had average greenhouse trials scores of 2.1, 2.3, 1.7, and 4.4 for tan spot races 1, 2, 3, and 5, respectively. Except for race 5, ND 756 scores to races 1, 2, and 3 were similar to the resistant check ‘Erik’ (PI 476849) scores (1.7, 1.3, and 1.3, respectively), and not significantly different from the scores of the other resistant check ‘Salamouni’ (PI 182673). Erik and Salamouni wheat cultivars are considered among the best resistance sources to tan spot. In the same trials, the susceptible check to races 1 and 2, ‘Glenlea’ (Cltr 17272), had scores of 3.7, 4.3, 2.0, and 1.9 for races 1, 2, 3, and 5, respectively. Glenn and Howard scores for the same races were 3.7 and 3.4, 3.9 and 3.3, 1.9 and 2.1, and 3.9 and 4.3, respectively. Under field conditions, ND 756 had similar resistant reaction (score of 2.0) as in the greenhouse tests to tan spot race 1 while Steele-ND, ‘Dapps’ (PI 633862; Mergoum et al., 2005b), and the susceptible check ND 495 scored 3, 3, and 5, respectively. The reaction to Ptr ToxA recorded based on the greenhouse trials, showed that ND 756 and Erik are insensitive while Howard, Glenn, and Glenlea are sensitive. However, the reaction of all these genotypes to Ptr ToxA toxin was sensitive.

The reaction of ND 756 to SNB, based on field and greenhouse trials, was 1.8 compared to 1.3 of the reaction of the resistant check Erik and 4.1, 3.6, and 3.6 ($P < 0.05$) scored for the susceptible checks Glenn, Howard, and Glenlea, respectively. ND 756 showed an insensitive reaction to the culture filtrate produced by P. nodorum isolate Sn2000 (Liu et al., 2004). A similar insensitive reaction was recorded for Erik while Glenn, Howard, and Glenlea were sensitive to the same culture filtrate.

The reaction of ND 756 to STB was 1.9 compared to 1.7 of the reaction of the resistant check Saloumni and 3.3 ($P < 0.05$), 2.2, and, and 3.7 ($P < 0.05$) scored for the susceptible checks ‘Granger’ (PI 636134), Howard, and ND 495, respectively.

Under severe FHB disease pressure, the disease severity (Stack and Frohberg, 2000) recorded on ND 756 from the filed scab nursery (21%) was significantly lower ($P < 0.05$) than the susceptible check ‘Reeder’ (PI 613586) (60%) and the very susceptible check ‘2398’ (74%). In the same trials, the average FHB severity recorded on Alsen, Glenn, Howard, Steele-ND, and ND 2710 was 24, 14, 31, 29, and 8%, respectively. Alsen was released in 2000 as the first NDSU HRSW cultivar with resistance to FHB and has been widely grown in ND since 2001. Howard and Steele-ND are both NDSU HRSW releases with FHB resistance derived from *Triticum dicoccoides* (Mergoum et al., 2006b; 2005a). Under greenhouse conditions, average FHB severity of ND 756 was 15.2% compared to 69 ($P < 0.05$), 20, 24, 11, 15, and 8% for 2398, Howard, Steele-ND, Alsen, Glenn, and ND 2710, respectively. Based on the same trials, visual scabby kernels of ND 756 (21%) was also very low ($P < 0.01$) compared to the susceptible check 2398 (74%), Reeder (60%); but similar to Alsen (24%), Steele-ND (29%), Howard (31%); and higher than the resistant check ND 2710 (8%).

Screening tests under greenhouse conditions showed that ND 756 exhibited a resistant reaction type to pathotype THBL, the predominant race of leaf rust in the region. Similarly, ND 756 was found to be highly resistant to the prevalent stem rust pathotypes Pgt-QCCJ,-QTHJ,-QFCQ,-RTQQ,-TPMK,-RHTS, and-HPHJ.

**Grain Yield Performance and Quality Parameters**

On the basis of the yield trials (AYTs and HRSW-VT) conducted in ND from 2001 to 2003, ND 756 mean grain yield (3990 kg ha-1) was comparable to Alsen (4057 kg ha-1) and Glenn (4179 kg ha-1), higher ($P < 0.05$) than the yield of Dapps (3620 kg ha-1), but lower than Steele-ND (4243 kg ha-1), and Howard (4380 kg ha-1).

Based on the HRSW-VT field trials, grain volume and protein content of ND 756 were, respectively, 782 kg m-3 and 15.2% compared to 785 kg m-3, and 15.2%; 784 kg m-3, and 15.3%; 810 kg m-3, and 15.6%; 781 kg m-3, and 15.4%; and 771 kg m-3 and 16.4% recorded for Alsen, Steele-ND, Glenn, Howard, and Dapps, respectively. Water absorption was 65.1%, similar to Reeder (64.3%), Alsen (65.2%), but slightly lower than Glenn (66.1%), Howard (66.5%), and Steele-ND (66.8%). Mixogram mix time (after 3 h fermentation) was 2.50 min, significantly longer ($P < 0.05$) than Reeder (1.95 min), but similar to Alsen (2.25 min), Glenn (2.5 min), Howard (2.25 min), and Steele-ND (2.10 min). The mixing tolerance score (16.6 min) was lower ($P < 0.05$) than Glenn (23.2 min), but similar to Alsen (17.9 min), Howard (18.2 min), and higher than Reeder (14.2 min). Loaf volume of ND 756 was 1010 mL compared to 1080, 1050, 1070, and 1072 mL of Glenn, Alsen, Howard, and Steele-ND, respectively. The flour yield of ND 756 was 680 g kg-1 which was 11, 12, and 17 g kg-1 less than Alsen, Glenlea, and Steele-ND, respectively.

**Seed Availability**

ND 756 should be of interest to many wheat breeders in the U.S. and worldwide where leaf spotting diseases SNB, STB, tan spot, and foliar diseases stem and leaf rusts, and FHB are major disease problems of wheat. ND 756 is a unique HRSW experimental line that combines resistance to leaf spotting diseases, a very good level of FHB resistance, good bread-making attributes, and high yield. Its relatively low grain protein content compared to current HRSW cultivars was the major reason it was not released.

The HRSW breeding program at NDSU will maintain the seed of ND 756. A seed sample has been deposited in the USDA-ARS National Center for Genetic Resources Preservation where it will become available for distribution in the future. Upon request to
the corresponding author, a small quantity of seeds of ND 756 can
be obtained for at least five years from the date of this publica-
tion for research purposes. Seed distribution for research purposes
will be done according to the provisions of the Wheat Worker’s
recognition of the source should be noted if ND 756 contributes
to research on leaf spots, rusts, and FHB, or to the development of
new genetic stocks, molecular tools, germplasm, or cultivars.

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