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Tolerance Expression of Maize Genotypes to *Exserohilum turcicum* in North and South Korea

Soon-Kwon Kim*†, Hyoung-Wook Kim*, Joon-Soo Lee**, Chang-Suk Huh***, Sun-Hwack Kim****, Kwang-Soo Lee****, and Hyoung-Jai Han****

*Handong International Corn Institute, Handong Global University, Pohang, Republic of Korea
**Natural Resources Research Institute, R&D Headquater, Korea Ginseng Corp., Daejeon, Republic of Korea
***Gyeongbuk Agricultural Administration of Gyeongbuk Province, Daegu, Republic of Korea
****Academy of Agricultural Sciences, Pyoungyang, Peoples' Republic of Korea

ABSTRACT Northern corn leaf blight caused by *Exserohilum turcicum* Pass is considered the most important disease infecting corn (*Zea mays* L.) in the Peoples' Republic of Korea (North Korea). It contributes to the food shortage in North Korea. The objectives of the current research were to study resistance expression and responses of corn crosses made between ten hybrids from North Korea and inbreeding lines ($S_{3\text{-}4}$ stage) from the Republic of Korea (South Korea). The experiments were conducted in six trials with a total of 184 crosses including two commercial hybrids in each trial. The trials were conducted at two locations in North Korea (Mirim and Eunsan) and one location in South Korea (Gunwi) under natural infestation of *E. turcicum*. Host plant responses were rated on a scale of 1 (highly tolerant) to 9 (highly susceptible). A total of 111 crosses (62.4%) showed significant tolerant or susceptible response variations among three locations; 42 crosses (22.8%) at two locations and 69 crosses (39.0%) at one location, respectively. At least 8 crosses of high level of tolerance and 12 crosses of high level of susceptibility showed significantly different biotic responses (P = 0.05). The results of the current study and historical reviews of *E. turcicum* epidemics in both North and South Korea suggest that breeding of tolerance with quantitatively inherited genes should be carried out for a sustainable corn production in North Korea.

Keywords : Northern corn leaf blight, NK × SK, Maize, Food shortage

Food shortages in the Democratic Peoples' Republic of Korea (DPRK), here after called North Korea or NK have been the center of world concern in recent years. Floods of 100 mm of rain daily for about ten days occurred in 1995 and 1996, and there were 50 days of drought in the spring and 12 m high tide hail in the west coast in September, 1997 leading to economic hardship and devastation of most of food production areas and farming systems in North Korea (Baker 1999; Kim 2000b; 2003; Kim *et al.*, 2001; Kim *et al.*, 2004).

Corn or maize (*Zea mays* L.) is the staple food in North Korea for 23 million people. It is the most widely cultivated crop (700,000 ha) followed by rice (600,000 ha), potato (200,000 ha) and soybean (150,000 ha, mostly intercropping with corn). Food shortage in North Korea may depend on production of corn, which is the staple food for 70% of the people. Ecological conditions for corn cultivation in North Korea are very favorable at the similar latitude as the US Corn Belt. Transplanting of month-old corn seedlings is a popular practice that requires extra labor. However, this technology is known to save growing time of the crop in the field and also to contribute to less growth of weed. Rice (*Oryza sativa* L.) is the staple food crop in the Republic of Korea (ROK), here after called South Korea or SK, but corn is the No. 1 grain used in the country. South Korea is the second largest importer of corn grain internationally (10 million metric tons annually) after Japan. The major uses are of feed and industrial raw materials (Kim *et al.*, 2001; Kim *et al.*, 2004).

The major constraints for corn production in North Korea according to the importance are the lack of fertilizers,

†Corresponding author: (Phone) +82-54-260-1787 (E-mail) kimsk@handong.edu
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seeds of high-quality stable high-yielding F_1 hybrids with easy seed production, northern corn leaf blight, which is caused by *E. turcicum* (formerly known as *Helminthosporium turcicum*), drought, stalk rots, and stem borers. Weak growth of the crop under low fertilizer application, spring drought, cold spells, and high rainfall in summer have contributed to high blight infection in North Korea.

Moderate temperature and heavy dew contribute to disease development. Reduction in grain yield depends on severity, time of disease infection, and host susceptibility. Susceptible hybrids lost yield of 40 to 68% when the disease became established by the time plants were in full silk and attained a high level of severity 2 to 4 weeks later (Ullstrup 1977).

The average reduction of grain yield by *E. turcicum* in North Korea is estimated to be 30% under severe infection. Historical data have shown that the highest damage of corn by the blight in the north was around 1975 when a hybrid, "SAR4", introduced from Yugoslavia was cultivated on about 50,000 ha. The major cause of the incidence was the break-down of the single gene of resistance, *Ht*1A. Within five years of its introduction, the hybrid was devastated by a new race of *E. turcicum* which created genetic vulnerability of the corn crop. In the late 1960s, a similar *E. turcicum* epidemic was experienced in South Korea when a double cross hybrid, Bokkyo #2 (Park *et al.*, 1975) was promoted in a major corn production area, Gangwon Province, on the border with North Korea. Resistance was also controlled by the same *Ht*1A. The mutant races of *E. turcicum* in the south and north might have drifted to the north and south, respectively, caused the disease epidemics in Korean Peninsula during the 1970s.

Breeding for *E. turcicum* resistance has been emphasized in both North and South Korea. The major source of resistance in North Korea was mostly from germplasm from the tropics, specifically Zimbabwe. While that in South Korea was mostly from US Corn Belt. The materials of the North Korea confer high level of stay-green characteristic with lateness that is also associated with the slow-drying down after physiological maturity. Early frost and rain in the fall often cause high infection of the ear and stalk rot.

By the request of the authority in Pyongyang, a collaborative research of corn breeding for North Korea was initiated in 1998 (Baker 1999). The program was targeted to increase corn production by 30% in the shortest possible time. The current research studied the genetic expression of tolerance to *E. turcicum* in both North and South Korea using the first experimental crosses made between North and South Korea germplasm (NK × SK). Racial variation of this disease in Korea Peninsula was investigated. This was the first scientific study made jointly by researchers from the both Koreas for host plant resistance or tolerance in North Korea.

MATERIALS & METHODS

Seeds of ten germplasm materials of corn (all F_1 hybrids) from the Academy of Agricultural Sciences in Pyongyang, North Korea were shared with the senior author in 1998. Detailed pedigrees were not provided. The materials with code number of NK 1 to 10 were crossed randomly with inbreeding lines matched with the flowering time in the winter - spring vinyl house nursery (Feb. - June, 1998) in Daegu, South Korea. A total of 184 F_1 test crosses were produced. Seeds of F_1 crosses were grouped into six trials with approximately 30 crosses in each trial. Two best commercial hybrids (DeKalb 729(DK 729) for silage and Pioneer 3394(P3394) for grain marketed in South Korea by the USA were included as checks in all six trials.

Materials were planted at two experiment stations (Mirim, near Pyongyang and Eunsan, South PyongAn Province, 100 km north from Pyongyang) of the Academy of Agricultural Sciences in North Korea and one station (Gunwi, North Kyungsang Province) of Kyungpook National University(KNU) in South Korea on 20 July (North Korea) and 25 July (South Korea) in 1998, respectively. Very high levels of natural infestation of *E. turcicum* were infected in all six trials at three locations. A one-month delay in plantings than in the regular season might contribute to the high and uniform infection. Due to the limited F_1 seeds, the trial was repeated only at Gunwi of South Korea in 1999.

The experiments were randomized in a complete block design with three replications; each plot consisted of one 2 - m row with 10 plants per row. Row and hill spacings of 0.75 and 0.25 m, respectively, gave a corn-planting density of 53,000 ha^{-1}. Fertilizers were applied at a rate of 60kg ha^{-1} each of N, 30 kg ha^{-1} P, and 50 kg ha^{-1} K as a compound fertilizer before planting in South Korea and 15 kg ha^{-1} each of N, 5 kg ha^{-1} P, and 10 kg ha^{-1} K in North Korea, respectively. An additional 50 kg ha^{-1} N in South Korea and 10 kg ha^{-1} N in North Korea were administered 4 weeks after planting. Fertilizers applied for respective locations were varied and followed the local recommendations.

The average visible blight symptoms on host plants per plot were rated at two weeks after mid-silking on a scale of 1 to 9 (1= highly tolerant, no blight symptoms; and 9 = highly susceptible, all plants blighted or scorched) (Hooker and Kim 1973; Kim 1974; Kim *et al.*, 1974). Details of the rating were as follows.

1 = highly resistant, no blight symptoms, hypersensitive response
2 = a mild blight symptom, a few lesions in the lower leaves, almost normal plant growth, highly tolerant.
3 = several lesions in the lower leaves with apparent tolerance symptoms, mild blotches
4 = some blotching with mild tolerance
5 = intermediate response between tolerance and susceptibility
6 = mild damage of host plant and little chance to recover
7 = some damage with little chance to recover
8 = apparent damage of plant causing significant yield reduction
9 = highly susceptible, severe damage of host plant with over 80% blighted

After a homogeneity test of two year data at Gunwi, the mean values of the three locations were used for statistical analysis. The mean squares of genotypes × location were used to test significance against genotypes and locations, respectively. All data were also calculated for percent trial mean (individual ratings divided by the trial mean of each trial) for better comparison of rating values of the six trials across three locations. Low percent values confer better tolerance than the high percent values. The mean percent value is 100%.

RESULTS AND DISCUSSION

Analyses of variances of six trials

Analyses of variances of ratings from the six trials showed that mean squares of tolerance scores of the test crosses (genotypes) were highly significant for three trials (I, II, and IV) and significant for three other trials (III, V, and VI). Mean squares across three locations were highly significant in Trial II (testers: NK 2, 3, 4) and significant in Trial VI (tester: NK10) (Table 1).

Mean ratings and percent trial means of test crosses

Mean ratings of 184 genotypes including commercial checks were arranged from the high tolerance to the high susceptibility in *Table 2* (ratings and percent trial means). Significant responses among three location values were expressed at p = 0.05 level. The grand mean of the 184 genotypes was 4.9 as intermediate of the 1 to 9 scale with 5.1 at Mirim, 4.8 at Eunsan and 5.0 at Gunwi, respectively.

Percent trial mean values of the crosses of NK2 × 80078 and NK1 × 80227 in Trial I and NK9 × 80128 in Trial V at the two locations in North Korea were considerably lower from those at Gunwi, indicating racial variation of

Table 1. Analysis of variances of six different trials with 184 crosses tested in North Korea (2 locations) and South Korea (1 location) for study of *E. turcicum* tolerance (1 - 9 rating scores) during 1998 and 1999

Sources	Trial Ⅰ		Trial Ⅱ		Trial Ⅲ		Trial Ⅳ		Trial Ⅴ		Trial Ⅵ	
	df	MS	df	MS	df	MS	df	MS	df	MS	df	MS
Genotype	32	3.28**	30	2.37**	29	2.77*	33	3.96**	34	2.96*	20	3.81*
Location	2	2.74	2	5.52**	2	0.70	2	0.02	2	2.31	2	4.33
Error	64	0.95	60	0.40	58	1.43	66	1.33	64	0.95	40	0.93

*, **: significance at p = 0.05 and 0.01, respectively. North Korea (Mirim and Eunsan), South Korea (Gunwi).

Table 2. Average rating scores and percent of trial mean of *E. turcicum* tolerance of 184 crosses of corn in six trials at 2 NK and 1 SK Stations (1998 and 1999)

Trial	Pedigree	Locations			Mean
		North Korea		South Korea	
		Mirim	Eunsan	Gunwi	
Trial I	NK2 × 80078	3.0 (53.2)	2.0*(38.4)	4.2(89.1)	3.1(57.8)
	NK1 × 80227	2.0*(35.5)	3.0*(57.6)	4.7(91.8)	3.2(61.6)
	NK1 × 80369	4.0 (71.0)	3.0*(57.6)	4.7(91.8)	3.9(73.4)
	NK1 × 80046	4.0 (71.0)	3.0*(57.6)	4.8(95.0)	3.9(74.5)
	NK1 × 80353	4.0*(71.0)	6.0(115.1)	5.2(101.6)	5.1(95.9)
	NK1 × 80173	5.0 (88.7)	6.0(115.1)	4.3*(85.2)	5.1(96.3)
	NK1 × 80348	7.0(124.2)	4.0*(76.7)	4.7*(91.8)	5.2(97.6)
	NK1 × 97A9108	8.0(141.9)	4.0*(76.7)	4.5*(88.5)	5.5(102.4)
	NK1 × 80113	7.0(124.2)	5.0*(95.9)	5.0*(98.3)	5.7(106.1)
	NK1 × 80155	7.0(106.5)	5.0*(115.1)	5.8(98.3)	5.9(106.6)
	NK1 × 80014	7.0(124.2)	6.0(115.1)	5.0*(98.3)	6.0(112.5)
	NK1 × 80246	8.0(141.9)	6.0(115.1)	4.8*(95.0)	6.3(117.4)
	NK1 × 80171	7.0(124.2)	7.0(134.3)	5.2*(101.6)	6.4(120.0)
	NK1 × 2051	7.0(124.2)	8.0(153.5)	5.2*(101.6)	6.7(126.4)
	NK1 × 80017	8.0(141.9)	7.0(134.3)	5.8*(114.7)	6.9(130.3)
	NK1 × 3070	9.0(159.7)	7.0*(134.3)	5.0*(98.3)	7.0(130.8)
	CK2 (P3394)	4.0* (71.0)	6.0(115.1)	5.3(104.9)	5.1(97.0)
	Mean	5.6	5.2	5.1	5.3
	LSD 0.05=				1.5
Trial II	NK3 × 80085	3.0(77.5)	2.0*(54.9)	3.3 (74.7)	2.8 (69.0)
	NK3 × 80167	3.0(77.5)	2.0*(54.9)	3.8 (85.9)	2.9 (72.8)
	NK3 × KHW1	2.0*(51.7)	3.0*(82.3)	4.3 (97.1)	3.1 (77.0)
	NK5 × 80025	3.0*(77.5)	2.0*(54.9)	4.7(104.6)	3.2 (79.0)
	NK5 × 80014	4.0(103.3)	2.0*(54.9)	3.8 (85.9)	3.3 (81.4)
	NK4 × 80130	3.0*(77.5)	3.0*(82.3)	4.0 (89.6)	3.3 (83.1)
	NK3 × 80069	3.0*(77.5)	3.0*(82.3)	4.0 (89.6)	3.3 (83.1)
	NK3 × 80148	3.0*(77.5)	3.0*(82.3)	4.5(100.8)	3.5 (86.9)
	NK3 × 80046	3.0*(77.5)	3.0*(82.3)	4.5(100.8)	3.5 (86.9)
	NK4 × 80128	3.0*(77.5)	3.0*(82.3)	4.5(100.8)	3.5 (86.9)
	NK3 × 80129	3.0*(77.5)	3.0*(82.3)	4.7(104.6)	3.7 (88.1)
	NK3 × 2051	3.0*(77.5)	3.0*(82.3)	4.7(104.6)	3.7 (88.1)
	NK2 × 80236	4.0(103.3)	3.0*(82.3)	3.7 (82.2)	3.6 (89.3)
	NK4 × 80138	4.0(103.3)	3.0*(82.3)	3.7 (82.2)	3.6 (89.3)
	NK3 × 80290	3.0 (77.5)	3.0 (82.3)	5.0*(112.0)	3.7 (90.6)
	NK4 × 80365	4.0(103.3)	3.0*(82.3)	4.0 (89.6)	3.7 (91.8)
	NK4 × 80137	3.0* (77.5)	4.0 (109.7)	4.3 (97.1)	3.8 (94.8)
	NK2 × 80212	4.0*(103.3)	5.0(137.2)	3.8*(85.9)	4.3(108.8)

Table 2. Average rating scores and percent of trial mean of *E. turcicum* tolerance of 184 crosses of corn in six trials at 2 NK and 1 SK Stations (1998 and 1999) -Continued

Trial	Pedigree	Locations			Mean
		North Korea		South Korea	
		Mirim	Eunsan	Gunwi	
Trial II	NK2 × 80286	4.0*(103.3)	5.0(137.2)	4.7(104.6)	4.6(115.0)
	NK4 × 2051	4.0*(103.3)	5.0(137.2)	4.8(108.3)	4.6(116.3)
	NK2 × 2051	6.0(155.0)	4.0*(109.7)	5.2(115.8)	5.1(126.8)
	NK2 × 80194	6.0(155.0)	5.0(137.2)	5.0*(112.0)	5.3(134.7)
	CK1 (DK729)	6.0*(155.0)	7.0(192.0)	6.8(153.1)	6.6(166.7)
	CK2 (P3394)	7.0(180.8)	6.0*(164.6)	5.3*(119.5)	6.1(155.0)
	Mean	3.9	3.6	4.5	4.0
	LSD 0.05=				1.0
Trial III	NK5 × 80026	3.0(64.3)	2.0*(40.8)	4.0(86.7)	3.0(63.9)
	NK5 × 80062	2.0*(42.9)	4.0(81.6)	4.7(86.7)	3.6(63.9)
	NK5 × 80058	3.0*(64.3)	3.0*(61.2)	5.0(108.4)	3.7(78.0)
	NK5 × 80283	2.0*(42.9)	5.0(102.0)	4.2(90.4)	3.7(80.0)
	NK5 × 80233	5.0(107.1)	3.0*(61.2)	4.7(101.2)	4.2(89.9)
	NK6 × 80022	3.0*(64.3)	6.0(122.4)	4.8(104.8)	4.6(97.2)
	NK6 × 80074	3.0*(64.3)	6.0(122.4)	4.8(104.8)	4.6(97.2)
	NK6 × 80147	4.0*(85.7)	6.0(122.4)	4.8(104.8)	4.9(104.3)
	NK5 × 80342	4.0*(85.7)	6.0(122.4)	4.8(104.8)	4.9(104.3)
	NK5 × 80344	4.0*(85.7)	6.0(122.4)	5.0(108.4)	5.0(105.5)
	NK5 × 80065	6.0(128.6)	4.0*(81.6)	5.0(108.4)	5.0(106.2)
	NK6 × 80146	8.0(171.4)	4.0*(81.6)	3.7*(79.5)	5.2(110.9)
	NK6 × 80127	7.0(150.0)	4.0*(81.6)	4.8*(104.8)	5.3(112.2)
	NK6 × 80138	7.0(150.0)	6.0(122.4)	4.2*(90.4)	5.7(120.9)
	NK5 × 80254	7.0(150.0)	7.0(142.9)	3.8*(83.1)	5.9(125.3)
	NK6 × 80123	7.0(150.0)	7.0(142.9)	3.8*(83.1)	5.9(125.3)
	CK2 (P 3394)	8.0(171.4)	8.0(163.3)	5.2*(112.0)	7.1(148.9)
	Mean	4.7	4.9	4.6	4.7
	LSD 0.05=				1.9
Trial IV	NK7 × 80379	3.0*(60.4)	2.0*(40.0)	5.2(104.4)	3.4(68.2)
	NK7 × 80375	3.0*(60.4)	3.0*(60.0)	4.8(97.6)	3.6(72.7)
	NK7 × 80371	5.0(100.6)	3.0*(60.0)	4.5(90.9)	4.2(83.8)
	NK6 × 80240	3.0*(60.4)	4.0*(80.0)	6.5(131.3)	4.5(90.5)
	NK7 × 80218	6.0(120.7)	3.0*(60.0)	4.7(94.3)	4.6(91.7)
	NK6 × 80347	3.0*(60.4)	6.0(120.0)	5.0(101.0)	4.7(93.8)
	NK7 × 80036	3.0*(60.4)	6.0(120.0)	5.5(111.1)	4.8(97.1)
	NK6 × 80370	4.0*(80.5)	6.0(120.0)	4.8(97.6)	4.9(99.4)
	NK6 × 2086	4.0*(80.5)	6.0(120.0)	5.0(101.0)	5.0(100.5)
	NK7 × 80177	7.0(140.8)	4.0*(80.0)	5.2(104.4)	5.4(108.4)

Table 2. Average rating scores and percent of trial mean of *E. turcicum* tolerance of 184 crosses of corn in six trials at 2 NK and 1 SK Stations (1998 and 1999) -Continued

Trial	Pedigree	Locations			Mean
		North Korea		South Korea	
		Mirim	Eunsan	Gunwi	
Trial IV	NK7 × 80074	5.0*(100.6)	7.0(140.0)	4.8*(97.6)	5.6(112.7)
	NK7 × 80057	8.0(160.9)	5.0*(100.0)	3.8*(77.4)	5.6(112.8)
	NK6 × 3070	6.0*(120.7)	8.0(160.0)	5.0*(101.0)	6.3(127.2)
	NK7 × 80051	6.0*(120.7)	8.0(160.0)	5.7(114.5)	6.6(131.7)
	NK6 × 80359	8.0(160.9)	8.0(160.0)	4.7*(94.3)	6.9(138.4)
	NK6 × 80355	8.0(160.9)	7.0(140.0)	5.7*(114.5)	6.9(138.5)
	CK2 (P 3394)	9.0(181.1)	7.0(140.0)	5.3*(107.7)	7.1(142.9)
	Mean	5.0	5.0	5.0	5.0
	LSD 0.05=				1.8
Trial V	NK9 × 80128	3.0(54.7)	2.0*(40.2)	4.7(89.3)	3.2(61.4)
	NK9 × 80016	4.0(72.9)	2.0*(40.2)	5.3(102.0)	3.8(71.7)
	NK7 × 3070	3.0*(54.7)	5.0(100.6)	4.8(92.4)	4.3(82.6)
	NK7 × KHW1	7.0(127.6)	3.0*(60.3)	4.7*(89.3)	4.9(92.4)
	NK10 × 80015	3.0*(54.7)	7.0(140.8)	4.3*(82.9)	4.8(92.8)
	NK7 × 80230	7.0(127.6)	3.0*(60.3)	4.8*(92.4)	4.9(93.5)
	NK8 × 80218	7.0(127.6)	4.0*(80.5)	4.0*(76.5)	5.0(94.9)
	NK10 × 80005	6.0(109.4)	5.0(100.6)	4.0*(76.5)	5.0(95.5)
	NK8 × 80096	4.0*(72.9)	6.0(120.7)	5.7(108.4)	5.2(100.7)
	NK9 × 3070	4.0*(72.9)	6.0(120.7)	6.3(121.1)	5.4(104.9)
	NK9 × 80045	7.0(127.6)	5.0*(100.6)	4.7*(89.3)	5.6(105.8)
	NK8 × 80335	4.0*(72.9)	7.0(140.8)	5.5(105.2)	5.5(106.3)
	NK8 × 80015	8.0(145.8)	4.0*(80.5)	5.0*(95.6)	5.7(107.3)
	NK9 × 80009	8.0(145.8)	4.0*(80.5)	5.7*(108.4)	5.9(111.6)
	NK8 × 80222	7.0(127.6)	5.0*(100.6)	5.7(108.4)	5.9(112.2)
	NK10 × 80008	5.0*(91.1)	7.0(140.8)	5.5(105.2)	5.8(112.4)
	NK9 × 80221	8.0(145.8)	5.0*(100.6)	5.8*(111.6)	6.3(119.3)
	NK9 × 2051	8.0(145.8)	6.0*(120.7)	5.2*(98.9)	6.4(121.8)
	NK8 × 80104	8.0(145.8)	7.0(140.8)	5.7*(108.4)	6.9(131.7)
	CK1 (DK729)	5.0*(91.1)	7.0(140.8)	7.2(137.1)	6.4(123.0)
	Mean	5.5	5.0	5.2	5.2
	LSD 0.05=				2.0
Trial VI	NK10 × 80026	3.0*(51.2)	3.0*(60.6)	4.5(84.4)	3.5(65.4)
	NK10 × 80252	3.0*(51.2)	3.0*(60.6)	5.0(93.8)	3.7(68.5)
	NK10 × 80231	4.0(68.3)	3.0*(60.6)	4.7(87.5)	3.9(72.1)
	NK10 × 80182	6.0(102.4)	3.0*(60.6)	4.2*(78.1)	4.4(80.4)
	NK10 × 80348	5.0(85.4)	4.0*(80.8)	6.0(112.5)	5.0(92.9)
	NK10 × 80250	6.0(102.4)	4.0*(80.8)	5.5(103.1)	5.2(95.4)

Table 2. Average rating scores and percent of trial mean of *E. turcicum* tolerance of 184 crosses of corn in six trials at 2 NK and 1 SK Stations (1998 and 1999) -Continued

Trial	Pedigree	Locations			Mean
		North Korea		South Korea	
		Mirim	Eunsan	Gunwi	
Trial VI	NK10 × 80044	6.0(102.4)	4.0*(80.8)	5.5(103.1)	5.2(95.4)
	NK10 × 80366	7.0(119.5)	5.0*(101.0)	5.2*(96.9)	5.7(105.8)
	NK10 × 80250	7.0(119.5)	5.0*(101.0)	5.3*(100.0)	5.8(106.8)
	NK10 × 80016	5.0*(85.4)	8.0(161.5)	5.2*(96.9)	6.1(114.6)
	NK10 × 80029	6.0(102.4)	7.0(141.2)	5.3*(100.0)	6.1(114.6)
	NK10 × 80253	7.0(119.5)	7.0(141.3)	5.0*(93.8)	6.3(118.2)
	NK10 × 2051	8.0(136.6)	6.0*(121.2)	6.0*(112.5)	6.7(123.4)
	NK10 × 80270	8.0(136.6)	7.0(141.3)	5.2*(96.9)	6.7(124.9)
	CK2 (P 3394)	8.0(136.6)	7.0(141.3)	6.2*(115.6)	7.1(131.2)
	Mean	5.9	5.0	5.3	5.4
	LSD 0.05=				1.5

Rating scores (1-9): 1= highly tolerant, 9=highly susceptible.
*: significant at p = 0.05 level. Non significant crosses were not included.
CK1; DeKalb 729, CK2; Pioneer 3394.

Table 3. Number (percentage) of corn crosses with significant variation for tolerance to *E. turcicum* at two and one location(s) in North and South Korea

Trial	Testers	Crosses	2 loc.	1 loc.	Total
I	NK 1, 2	33	5 (15.2)[1)]	12 (36.4)	17 (51.5)
II	NK 2, 3, 4	31	12 (38.7)	12 (38.7)	24 (77.4)
III	NK 5, 6	30	3 (10.0)	14 (46.7)	17 (56.7)
IV	NK 6, 7	34	6 (17.6)	11 (32.4)	17 (50.0)
V	NK 7, 8, 9, 10	35	9 (25.7)	11 (32.2)	20 (57.9)
VI	NK 10	21	7 (33.3)	10 (47.6)	17 (80.9)
Total		184	42 (22.8)	69 (39.0)	111 (62.4)

1); Percent.

E. turcicum in Korea Peninsular (Table 2).

Crosses with significant differences

In the summary of the results, 111 crosses (62.4%) of the total of 184 crosses showed significant tolerant or susceptible responses in test locations; 42 crosses (22.8%) at two locations and 69 crosses (39.0%) at one location, respectively (Table 3). Among the six trials, the highest variations were observed in Trial VI with 17 crosses (80.9%) and Trial II with 24 crosses (77.4%), while the lowest variations were observed in Trial IV with 17 crosses (50.0%) and Trial I with 17 crosses (51.5%). The high significant variation in tolerance confirms yet again the racial variation of *E. turcicum*.

In the summary of two-location significance, Trial II and Trial VI had 12 crosses out of the 31 crosses (38.7%) and 7 out of the 21 crosses (33.3%), while in one location significance, Trial VI and Trial III had 10 crosses out of the 21 crosses (47.6%) and 14 crosses out of the 30 crosses (46.7%), respectively.

Highly tolerant crosses

At least eight crosses with high levels of tolerance (4.3%) showed significantly different responses ($p = 0.05$) (Table 4). Grand mean rating score of the eight highly tolerant crosses selected was 3.3 (66.1 percent mean). Individual rating means of Mirim, Eunsan, and Gunwi were 3.0 (58.6 percent mean), 2.5 (56.8 percent mean), and 4.4 (82.8 percent mean), respectively. The mean tolerance scores of the crosses at the two North Korea locations were less than 60% percent trial means that were significantly higher than that at South Korea. The ten test materials used in this study were bred from Eunsan and Mirim Research Stations in North Korea. Three crosses (NK1 × 80227 from Trial I, NK10 × 80026, NK10 × 80252 from Trial VI) showed significantly high tolerance at Mirim, while all eight selected crosses showed significantly high tolerance at Eunsan (Headquarter research station of corn in North Korea). None of the eight selected crosses at Gunwi in South Korea showed significant responses for tolerance, indicating that race of South Korea might be less aggressive than those in the two NK stations where corn cultivation is much more intensified.

Highly susceptible crosses

At least 14 crosses with a high level of susceptibility showed significantly different responses ($p = 0.05$) (Table 5). Except for Trial V, 2 to 4 crosses from each trial

Table 4. Summary of tolerance scores (1-9) and percent trial means (parenthesis) of selected 8 crosses with significantly more tolerant to *E. turcicum* than others from 184 crosses tested in North and South Korea

Trial	Pedigree	Locations			Mean
		Mirim	Eunsan	Gunwi	
I	NK2 × 80078	3.0 (53.2)	2.0* (38.4)	4.2 (81.9)	3.1 (57.8)
	NK1 × 80227	2.0* (35.2)	3.0* (57.6)	4.7 (91.8)	3.2 (61.6)
II	NK3 × 80085	3.0 (77.5)	2.0* (54.9)	3.3 (74.7)	2.8 (69.0)
	NK3 × 80167	3.0 (77.5)	2.0* (54.9)	3.8 (85.9)	2.9 (72.8)
III, IV			Not selected		
V	NK9 × 80128	3.0 (54.7)	2.0* (40.2)	4.7 (89.3)	3.2 (61.4)
VI	NK10 × 80026	3.0* (51.2)	3.0* (60.0)	4.5 (84.4)	3.5 (65.4)
	NK10 × 80252	3.0* (51.2)	3.0* (60.6)	5.0 (93.8)	3.7 (68.5)
	NK10 × 80231	4.0 (68.3)	3.0* (87.5)	4.7 (60.6)	3.9 (72.1)
Mean		3.0 (58.6)	2.5 (56.8)	4.4 (82.8)	3.3 (66.1)

Rating scores (1-9): 1= highly tolerant, 9=highly susceptible.
*: significant at p =0.05 level.

Table 5. Summary of susceptibility scores (1-9) and percent trial means (inside parenthesis) of selected 14 crosses with significantly more susceptible to *E. turcicum* than others from 184 crosses tested in North and South Korea

Trial	Pedigree	Locations			Mean
		Mirim	Eunsan	Gunwi	
I	NK1 × 3070	9.0* (159.7)	7.0* (134.3)	5.0* (98.3)	5.3 (130.3)
	NK1 × 80017	8.0* (141.9)	7.0 (134.3)	5.8 (114.7)	6.9 (130.8)
II	NK2 × 80194	6.0* (155.0)	5.0 (137.2)	5.0 (112.0)	5.3 (134.7)
	NK2 × 2051	6.0* (155.4)	4.0 (137.2)	5.2* (112.0)	5.1 (126.8)
	DK729	6.0 (155.0)	7.0* (192.0)	6.8 (153.1)	6.6 (166.7)
	P3394	7.0* (180.8)	6.0 (164.6)	5.3 (119.5)	6.1 (155.0)
III	DK729	8.0 (171.4)	7.0 (142.9)	6.2 (133.7)	7.1 (149.3)
	P3394	8.0* (171.4)	8.0* (163.3)	5.2 (112.0)	7.1 (148.9)
IV	DK729	8.0 (160.9)	7.0 (140.0)	7.5 (151.5)	7.5 (150.8)
	P3394	9.0* (181.1)	7.0 (140.0)	5.3 (107.7)	7.1 (142.9)
	NK6 × 80359	8.0* (160.9)	8.0* (160.9)	4.7 (94.3)	6.9 (138.4)
	NK6 × 80355	8.0* (160.9)	7.0 (140.0)	5.7 (114.5)	6.9 (138.5)
V			Not selected		
VI	DK729	7.0 (119.5)	7.0 (141.3)	7.5 (140.6)	7.2 (133.8)
	P3394	8.0* (136.6)	7.0 (141.3)	6.2 (115.6)	7.1 (131.2)
Mean		7.6 (159.7)	6.7 (147.7)	5.8 (120.0)	6.6 (141.3)

Rating scores (1-9): 1= highly tolerant, 9=highly susceptible.
*: significant at p=0.05 level.

showed high susceptibility including two commercial hybrid checks from four trials (Trial II, III, IV and VI).

The grand mean rating score of eight selected highly susceptible crosses was 6.3 (141.3 percent mean). Individual mean ratings and percent trial mean of Mirim, Eunsan and Gunwi were 7.6 (157.9 percent mean), 6.7 (147.7 percent mean) and 5.8 (120.0 percent mean), respectively. Susceptibility scores from two North Korean locations were significantly higher than those scores from South Korea. The generally low infection of the disease in the Gunwi environment might have affected the rating scores. At Mirim, 10 crosses except DK729 in Trial II, Trial III, IV, and VI showed significantly high susceptibility. At Eunsan, only four crosses (NK1 × 3070 in Trial I, DK729 in Trial II, P3394 in Trial III, and NK6 × 80359 in Trial IV) showed significantly higher susceptibility. 3070 was the code of a

USA sweet corn hybrid, Golden Cross Bantam, controlled by *su* gene marketed in South Korea. At Gunwi, only one cross (NK2 × 2051 in Trial II) showed significantly higher susceptibility than the others. 2051 was coded of a USA commercial super-sweet corn hybrid, Cocktail 51, controlled by *sh*2 gene in South Korea. Aggressiveness of *E. turcicum* race at Mirim, less tolerance breeding research carried out, and high infection environments (low temperature and high rainfall) at Mirim Station might have contributed to the highly significant susceptible levels of more crosses. Corn is also very widely grown in the most of upland fields in Pyongyang.

Mean tolerance ratings of two commercial checks

High infections of *E. turcicum* in six trials from three locations are summarized in Table 6. The average ratings of two checks across the six trials and three locations were 6.9 (140.6 percent mean) for DK 729 and 6.6 (135.1 percent mean) for Pioneer 3394. DK 729 rated equally susceptible scores at Mirim 6.8 (137.0 percent mean), Eunsan 6.8 (145.4 percent mean) and Gunwi 6.9 (141.8 percent mean). Pioneer 3394 rated susceptible scores at

Table 6. Tolerant rating scores (1-9) and percent trial means (inside parenthesis) of two commercial hybrid checks to *E. turcicum* included in six trials tested in North Korea (2 locations) and South Korea (1 location)

Trial	Pedigree	Locations			Mean
		Mirim	Eunsan	Gunwi	
I	DK729	7.0 (124.2)	6.0 (115.1)	6.2 (121.3)	6.4 (120.2)
	P3394	4.0* (71.0)	6.0 (115.1)	5.3 (104.9)	5.1 (97.0)
II	DK729	6.0* (155.0)	7.0 (192.0)	6.8 (166.7)	6.6 (166.7)
	P3394	7.0 (180.8)	6.0* (164.6)	5.3* (119.5)	6.1 (155.0)
III	DK729	8.0 (171.4)	7.0 (142.9)	6.2 (133.7)	7.1 (149.3)
	P3394	8.0 (171.4)	8.0 (163.3)	5.2* (112.0)	7.1 (148.9)
IV	DK729	8.0 (160.9)	7.0 (140.0)	7.5 (151.5)	7.5 (150.8)
	P3394	9.0 (181.1)	7.0 (140.0)	5.3 (107.7)	7.1 (142.9)
V	DK729	5.0* (91.1)	7.0 (140.8)	7.2 (137.1)	6.4 (123.0)
	P3394	7.0 (127.6)	8.0 (160.9)	6.2 (117.9)	7.1 (135.5)
VI	DK729	8.0 (119.5)	7.0 (141.3)	7.5 (140.6)	7.2 (133.8)
	P3394	8.0 (136.6)	7.0 (141.3)	6.2 (115.6)	7.1 (131.3)
Mean	DK729	6.8 (137.0)	6.8 (145.4)	6.9 (141.8)	6.9 (140.6)
	P3394	7.2 (144.8)	7.0 (147.5)	5.6 (112.9)	6.6 (135.1)

Rating scores (1-9): 1= highly tolerant, 9=highly susceptible.
*: significant at p = 0.05 level.

Mirim 7.2 (144.8 percent mean), Eunsan 7.0 (147.5 percent mean) and moderate at Gunwi 5.6 (112.9 percent mean), respectively. The latter hybrid showed high susceptibility to the southern corn leaf blight caused by *Bipolaris maydis* at Gunwi(Table 6).

The results of this study prove that employment of proper breeding technology for host durability is an important step to increase crop stability under various biotic conditions. In 2001 and 2002, severe epidemics of *E. turcicum* infection were experienced in many locations in North Korea including Ryoungchun, Gaecheon, Onggin, and areas of Yanggang and Jagang Provinces. An average reduction of 30% yield might be occurred by susceptible cultivars under epidemic conditions. High rainfall and cold weather during the summer season contribute to producing the high blight infections in North Korea where corn is the dominant crop in the upland.

Since *E. turcicum* is the most destructive disease of the staple food corn in North Korea, breeding cultivars for tolerance or durable resistance genes are important. This can be another way of increasing food production in the country. Because of the historical incidences of *Ht*1A gene - with highly resistant hypersensitive type controlled of SAR4 in North Korea and the Bokkyo hybrid in South Korea (Kim *et al.*, 2001; Park *et al.*, 1975), horizontal resistance or tolerance has been emphasized since 1998 to minimize the directional selection pressures against race specific - high resistance genes. This approach has been employed not only for corn, but also for rice, potatoes and soybeans.

Host × pathogen interactions of *E. turcicum* race-specific resistance genes (e.g. *Ht*1A, *Ht*1B etc.) have been studied by many research groups (Brewbaker *et al.*, 2011, 1990; Hooker 1963; Hooker 1978; Hughes and Hooker 1971; Jenkins and Rober 1958; Kim *et al.*, 1988). The efficacy of near iso-genetic genes of specific resistance has been also studied extensively (Hooker and Kim 1973; Kim *et al.*, 1974).

From the test materials in the current study, observations of racial variation of corn genotypes against *E. turcicum* tolerance in Korea Peninsula were made first at the KNU Gunwi Research Station in South Korea, and later Mirim Research Station in Pyongyang and Eunsan Corn Research Station in North Korea in both 1998 and 1999. Some plants showed both highly resistant (mono-gene controlled) and tolerant (poly-gene controlled) symptoms in a plant at a testing station, indicating the presence of race variation of the pathogen.

A mutant race of *E. turcicum* resistance was reported in Hawaii (Berquist and Masias 1974). A resistant maize population 44 from CIMMYT, Mexico for the mid-altitude ecology in the East and Southern Africa showed high susceptibility in a mid-altitude station in Jos, Nigeria (Kim 2003; Kim *et al.*, 1985), indicating racial differences in the continent of Africa. *E. turcicum* is considered the second most damaging disease of corn in Cameroon, Kenya, and Uganda (Eberhart *et al.*, 1991; Everett *et al.,* 1994a; Everett *et al.*, 1994b; Kim *et al.*, 2003).

Numerous examples of the breakdown of a single gene for high resistance have been reported with other biotic stresses including *Puccinia sorghi* (Kim and Brewbaker 1976, 1977), *P. polysora* (Brewbaker *et al.*, 2011; Kim 1993; Kim *et al.*, 1988), *B. maydis* (Kim *et al.*, 1988), maize streak virus (Kim *et al.*, 1989), and *Striga hermonthica* (Kim 1994a; Kim 1994b; Kim 1996). The importance of quantitatively inherited genes for tolerance against diseases, parasitic weeds, and insects has been studied by many groups in details (Brewbaker 1974; Brewbaker *et al.*, 1990, 2011; Carson and Van Dyke, 1994; Kim 1993, 2002; Nelson 1973; Pataky 1994; Robinson 1996; Van der Plank 1968; Zadocks 1993).

Breeding for mono-gene controlled hypersensitive types of high resistance is a dangerous approach to sustain durability of resistance. Tolerance or horizontal resistance must be pursued (Brewbaker *et al.*, 2011; Kim 1993a, 1993b, 1994a, 1994b, 1996, 2000a). However, scientists of most developing countries still look for race-specific type of high resistance (Brewbaker *et al.*, 2011; Kim 2000a).

In nature, pests and hosts must co-survive. If any one side dominates the other, mutation of a new biotype occurs naturally to promote co-survival. Tolerance and durable resistance technology can be called as the Genetic Integrated Pest Management (Kim 2000b, 2003b; Kim and Brewbaker 1976; Kim *et al.*, 2004). A crop cultivar that withstands with pests in nature confers very powerful tolerance compare to the high resistance + chemical spray + others. For environmentally friendly green food production, the host tolerance may be the key for the crop stability. Other researchers have referred to this principle as horizontal resistance (Van der Plank 1968), durable resistance (Zadocks 1993), general resistance (Brewbaker *et al.*, 2011; Brewbaker 1983), generalized resistance (Hooker, 1978), field resistance (Van der Plank, 1968), race-non specific resistance (Nelson 1973; Van der Plank 1968), and partial resistance (Carson and Van Dyke 1994; Pataky 1974).

The strategy for developing *E. turcicum* tolerance in North Korea has taken two approaches; the first is to develop tolerance hybrids and the second is to form open-pollinated synthetic or composite cultivars using selected tolerance inbred lines and crosses. Since 2002, three synthetics(Syn.) by the name of NK Syn. Early, NK Syn. Middle, and NK Syn. Lately. according to maturities were formed. A similar approach of the resistance synthetic formation by the name of Mmaize Inbred Resistance was adopted by researchers at the University of Hawaii to control *E. turcicum* in the tropics (Brewbaker *et al.*, 1990).

The weakness of this study is that limited data collected from only two locations in North Korea for one year and one location for two years in South Korea. However, number of F_1 crosses between NK germplasm and SK breeding lines were considerable. The interpretation of the data by both visual rating scores (1-9) and percent trial means has support the high value of this paper. The way of the latter statistical analysis is known to be outstanding value comparison among different environments (Brewbaker, Kim unpublished). Further studies with different sets of diallel crosses with inbred parents will argue the results of the data presented here.

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