INHERITANCE OF POWDERY MILDEW RESISTANCE GENES

IN 10 WINTER WHEAT LINES

by

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(ABSTRACT)

Ten winter wheat (*Triticum aestivum* L.) lines selected from the 1982 International Winter Wheat Mildew and Rust Nurseries were studied to characterize gene number and mode of inheritance of powdery mildew resistance. Two experiments were conducted: 1) each of the lines was crossed to the susceptible cultivar Chancellor, which lacks any known gene for resistance, and seedlings of the parental lines, F_1, F_2, BC_1 (Chancellor $\times$ F_1), and F_3 populations were inoculated with isolate 127 of *Blumeria graminis* (DC.) E. O. Speer f. sp. *tritici* Em. Marchal in the greenhouse and evaluated for powdery mildew reaction; 2) the ten lines were crossed with each other and to each of 13 host differential lines with known genes for powdery mildew resistance, and 300 to 800 F_2 seedlings from each cross were evaluated. All parents were resistant (Infection Type = 1-3), except for ST1-25, which had an intermediate (IT = 4-5) reaction type. Genetic analyses of crosses revealed that the resistance in C39 and SI5 is

conferred by three dominant genes (*Pm*2, 4b, and 6), and resistance in A55-2, R107, and Bulk PV63-6 is governed by one partially dominant gene (*Pm*4b). Results from F_2, F_3, and BC_1 populations derived from crosses between 'Armada' and Chancellor, were inconsistent, but indicated that Armada has at least one dominant gene for resistance, which likely is *Pm*4b as suggested by others. The resistance gene in OK75R3645 most likely is an allele at the *Pm*3 locus, and it is probable that the resistance gene in GO4779 is *Pm*1. Single recessive genes were identified in VPM1 (*Pm*4b) and ST1-25 (*Pm*8).

Dedication

To my wife Misuk and my daughter HyunJu

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INTRODUCTION

Powdery mildew, caused by *Blumeria graminis* (DC.) E. O. Speer f. sp. *tritici* Em. Marchal, is one of the most prevalent and destructive diseases of wheat (*Triticum aestivum* L.) worldwide (Bennett, 1984). It has been shown in the United States that approximately 10 to 35% yield reduction can be caused by this disease (Frank and Ayers, 1986; Leath and Bowen, 1989; Lipps and Madden, 1988).

Among the strategies for controlling powdery mildew, genetic resistance has provided the most effective and efficient means, and provides the advantage of environmental safety and economical feasibility. Genetic resistance to powdery mildew, which is the result of host-pathogen interactions (Flor, 1955), has been studied for more than 40 years. Due to these serious efforts, 20 race-specific resistance genes have been identified (McIntosh, 1988; Zeller et al., 1993), and some of the resistance genes have been incorporated and widely used in commercial cultivars. However, lack of information on the identity of resistance genes present in many cultivars has hindered the most efficient use of these limited number of effective resistance genes. This useful information can be obtained by genetic studies which provide reliable information on inheritance and characterization of the underlying resistance (Heun and Fischbech, 1989; Lowry et al., 1984).

The present study includes the results obtained from genetic characterization of powdery mildew resistance in 10 selected winter wheat lines which were previously studied by Jeyandran (1984, M.S. Thesis). The objectives of this study were: 1) to characterize gene number and mode of inheritance of powdery mildew resistance in 10 winter wheat lines; 2) to determine if the 10 resistant parents have genes in common; 3) to confirm the previous estimates of gene number in resistant parents through the evaluation of populations in which segregation occurred; and 4) to determine if the parents have unique resistance genes.

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Chapter I

Gene Number and Mode of Inheritance

ABSTRACT

Ten winter wheat (*Triticum aestivum* L.) lines selected from the 1982 International Winter Wheat Mildew and Rust Nurseries were studied to characterize gene number and mode of inheritance of resistance to powdery mildew, caused by *Blumeria graminis* (DC.) E. O. Speer f. sp. *tritici* Em. Marchal. Each of the lines were crossed to the susceptible cultivar Chancellor which lacks any known gene for resistance. Seedlings of the parental lines, F_1, F_2, BC_1 (Chancellor $\times F_1$), and F_3 populations were inoculated with isolate 127 of *B. graminis* and evaluated for powdery mildew reaction. All parents were resistant (Infection Type = 1-3), except for ST1-25, which had an intermediate (IT = 4-5) reaction type. Genetic analyses of crosses revealed that the resistance in C39 and SI5 is conferred by three dominant genes, and resistance in A55-2, R107, GO4779, OK75R3645, and Bulk PV63-6 is governed by single partially dominant genes. Data from F_2, F_3, and BC_1 populations derived from crosses between Armada and Chancellor were inconsistent, but indicated that Armada has at least one dominant gene for resistance, which likely is *Pm*4b as suggested by others. Resistance in VPM1 and ST1-25 is governed by one recessive gene in each line.

INTRODUCTION

Powdery mildew, caused by *Blumeria graminis* (DC.) E. O. Speer f. sp. *tritici* Em. Marchal, is one of the most prevalent and destructive diseases of wheat (*Triticum aestivum* L.) in the southeastern and mid-Atlantic regions of the United States (Bowen et al., 1991). Resistance governed by race-specific major genes has been used extensively in breeding programs to control powdery mildew because it is readily incorporated into desirable genotypes and provides an economical and environmentally safe means of disease control (Bennett, 1984). However, qualitative resistance can be overcome by isolates of the pathogen possessing corresponding virulence genes as described by Flor (1955) in studies on host-pathogen interactions. Virulence to the 10 most widely used resistance genes for powdery mildew has been identified in the southeastern United States (Leath and Murphy, 1985). In an attempt to replace these defeated resistance genes, new sources of resistance have been searched for in related species and genera (Briggle, 1966a,b; Jørgensen and Jensen, 1972, 1973; Lebsock and Briggle, 1974). As of 1988, 17 race-specific resistance genes have been identified (McIntosh, 1988). Recently, three new alleles at the *Pm*3 locus were identified (Zeller et al., 1993a).

Due to the limited number of genes for powdery mildew

resistance, it is necessary to use all available genes in combinations that will provide effective resistance with greater stability. This can be facilitated through a better understanding of changes in virulence in the pathogen population and the genetics of host resistance. There have been useful reports on virulence genes and their frequency in the United States, Canada, and Germany (Bailey and MacNeil, 1983; Heun, 1987; Leath and Murphy, 1985; Namuco et al., 1987). This information is valuable for the deployment of effective resistance genes and in the recommendation of cultivars which contain such genes.

Genes for powdery mildew resistance in winter and spring wheat cultivars have been identified in the United States and Europe (Leath and Heun, 1990; Heun and Fischbeck, 1987a,b; Lutz et al., 1992; Zeller et al., 1993b). This research has provided useful information on the genetic basis for powdery mildew resistance in wheat. However, available information on the identity of resistance genes present in many cultivars is still lacking; therefore, many researchers have used selected sets of *Blumeria graminis* f. sp. *tritici* cultures, which vary in their virulence, to postulate the identity of such genes. Also, little is known concerning the frequency of resistance genes among wheat cultivars, and relatively few inheritance studies have been reported in comparison to other host-pathogen systems in wheat.

Inheritance studies provide additional and often more reliable information on the underlying genetics of resistance than is achieved in studies aimed at postulating genes based on host reaction to a set of differential pathogen isolates (Heun and Fischbech, 1989; Lowry et al., 1984; Sebastian et al.,1983).

A previous study on the inheritance of powdery mildew resistance using the same wheat lines investigated in the current study was conducted by Jeyandran (1984, M.S. thesis), in which the "Quincy" isolate was used. Jeyandran postulated that GO4779 had a dominant resistance gene at the *Pm1* locus and that the other lines each had single recessive genes, which were not located at the *Pm1* or *Pm3* loci. However, results from this study were indecisive and were not published. The objective of the current genetic study, therefore, was to characterize gene number and mode of inheritance of powdery mildew resistance in 10 winter wheat lines, previously studied by Jeyandran.

MATERIALS AND METHODS

Genetic populations and *Blumeria graminis* f. sp. *tritici* isolate

Ten winter wheat lines selected from the 1982 International Winter Wheat Mildew and Rust Nurseries were used in this genetic study, because they were reported to possess resistance to powdery mildew (Table 1). These resistant parents were crossed to a susceptible cultivar Chancellor, which lacks any known powdery mildew resistance gene. The F_1 seeds obtained from these crosses were planted to produce F_2 populations and to develop BC_1 populations (Chancellor $\times F_1$). One hundred seeds from each of three individual F_1 plants of each cross were space-planted in the field, and 300 F_2 plants from each cross were harvested and threshed individually. F_3 seed from 100 randomly selected F_2 plants was used in evaluations of genotypic ratios of F_2 populations.

Blumeria graminis f. sp. *tritici* isolate 127 (provided by Dr. S. Leath, North Carolina State University), previously described by Leath(1990) and Moseman et al. (1984), was used in this study. The virulence / avirulence formula proposed by Moseman et al. (1984) for isolate 127 and that observed in the current study was: *Pm*3b, 3c, 5, 7/ *Pm*1, 2, 3a, 4a, 4b, 6, 8, 17. Virulence for *Pm*8 was partially expressed, and intermediate host reactions were generally observed.

Greenhouse Evaluation

A set of plant materials from each cross, comprised of 10 seeds of parental lines, 3 to 23 F_1, 250 to 850 F_2, 50 to 80 BC_1, and 50 to 100 seeds per F_3 family, was planted in plastic pots (75 mm in diameter and 65 mm in depth) containing a commercial potting medium. The pots were placed in wooden flats (35 pots per flat), and the flats were arranged randomly on a greenhouse bench maintained at 21 ± 4 °C. In addition, twenty powdery mildew differential host lines were planted with each set of experiments and were used to detect possible contamination. Inoculum of *B. graminis* f. sp. *tritici* isolate 127 was produced and maintained on seedlings of the susceptible cultivar Barbee. Plant materials were inoculated at the one- to two-leaf stage(10-12 days after planting). Infected Barbee seedlings were held about 20 cm over the plant materials and shaken to cause conidia to fall onto the leaves of plants to be inoculated. After 24 hours, the same inoculation procedure was repeated to ensure uniform inoculation. The inoculated plant materials were maintained on the greenhouse bench for an additional 10-12 days before evaluation. Each set of plant materials was tested once in most cases due to limited availability of seeds. However, some plant materials were retested to elucidate unexpected results.

Infection type (IT) was assessed according to the

modified scale of Moseman et al. (1984) where 0 = immune, no visible sign of infection; 1 to 3 = resistant, increasing from flecks with no necrosis to large necrotic areas and increasing from no mycelium to few mycelium; 4 to 6 = moderately resistant, necrotic areas changing to chlorotic areas and increasing amount of mycelium and conidiospore production; and 7 to 9 = susceptible, decreasing from chlorotic areas to no chlorosis and increasing amounts of mycelium and conidia production to a completely compatible reaction. From this scale, three major reaction type classes were designated as resistant (IT = 0-3), intermediate(IT = 4-6), and susceptible(IT = 7-9) and were used to estimate gene number by Chi-square analysis.

RESULTS

The 10 resistant parents were inoculated to *B. graminis* f. sp. *tritici* isolate 127 to determine their infection types. All of these parents were resistant (IT = 1-3), except for ST1-25 whose infection type was 4 to 5 (Table 1). Estimates of gene numbers and mode of inheritance were determined from analysis of infection types of the parents and F_1, and from segregation patterns of F_2, BC_1, and F_3 populations (Tables 1-3).

Chancellor × C39

Chancellor, C39, and their F_1 had infection types of 9, 1, and 1 to 2, respectively. The observed segregation pattern in the F_2 population fit a 63 resistant(R):1 susceptible(S) ratio (Table 2). This indicated that the resistance in C39 was conferred by three dominant genes. The BC_1 population segregated for 7R:1S, and supported the hypothesis that C39 has three genes. Classification of 100 F_3 families according to disease reaction types observed within each family fit an F_2 genotypic ratio of 37:6:12:8:1 (Table 3), which was expected for the segregation of three independent dominant genes. Based on results from F_2, F_3, and BC_1 populations, it can be concluded that resistance in C39 is conditioned by three dominant genes.

Chancellor × A55-2

Infection types of Chancellor, A55-2, and their F_1 were 9, 1, and 4 to 5, respectively. The F_1 reaction indicated that resistance in A55-2 was not completely dominant in this case. The F_2 population segregated for 102 resistant plants, 215 plants with an intermediate reaction type, and 93 susceptible plants (Table 2). This segregation pattern fit a 1:2:1 ratio and indicated that resistance in A55-2 is conditioned by a single gene with partial dominance. This was confirmed in analysis of the BC_1 population in which a 1I:1S segregation ratio was observed. Classification of 97 F_3 families resulted in 25 homozygous resistant families, 51 families segregating 3R:1S, and 21 homozygous susceptible families, which fit a 1:2:1 F_2 genotypic ratio. This result supports the hypothesis that A55-2 has one partially dominant gene for resistance to powdery mildew.

Chancellor × R107

Infection types of R107 and Chancellor were 1 and 9, respectively. The intermediate reaction (IT = 3-5) of 14 F_1 plants suggested that resistance in R107 was only partially dominant. The observed segregation pattern in the F_2 population fit a 1R:2I:1S ratio (Table 2). Segregation in the backcross population resulted in 40 intermediate and 35

susceptible plants, and fit a 1I:1S ratio. The hypothesis for one resistance gene in R107 was confirmed in the analysis of F_3 lines, in which 25 homozygous resistant lines, 52 lines segregating 3R:1S and 24 homozygous susceptible lines were observed (Table 3). This classification of F_3 lines fit the expected F_2 genotypic ratio of 1:2:1.

Chancellor × GO4779

Chancellor and GO4779 had infection types of 9 and 1 to 3, respectively. Infection types of 13 F_1 plants ranged from 3 to 4, and suggested that resistance in GO4779 was partially dominant. The observed F_2 segregation pattern of 329(R+I):120(S) fit a 3:1 ratio and indicated that GO4779 has one partially dominant gene for resistance (Table 2). The segregation of 33(R+I):39(S) in the BC_1 population fit a 1:1 ratio, which supported the hypothesis for one resistance gene. Classification of F_3 lines for disease reaction resulted in 23 homozygous resistant lines, 49 lines segregating 3R:1S, and 28 homozygous susceptible lines (Table 3). This data fit a 1:2:1 F_2 genotypic ratio and provided further evidence that GO4779 has one partially dominant resistance gene.

Chancellor × OK75R3645

The observed infection types of Chancellor (IT = 9),

OK75R3645 (IT = 3), and their F_1 (IT = 4-5) indicated that resistance in OK75R3645 was partially dominant. The observed segregation pattern in the F_2 population with 138 resistant, 292 intermediate, and 147 susceptible plants fit a 1:2:1 monogenic ratio (Table 2). Segregation in the BC_1 population conformed to a 1I:1S ratio and confirmed the hypothesis that OK75R3645 has one gene for resistance to powdery mildew. The F_3 lines were classified as 19 homozygous resistant, 56 segregating 3R:1S, and 25 homozygous susceptible (Table 3). The hypothesized F_2 genotypic ratio of 1:2:1 was accepted. Results from this cross inferred the presence of one partially dominant gene in OK75R3645.

Chancellor × Armada

The infection types of Chancellor and Armada were 9 and 1 to 3, respectively. The disease reaction of F_1 plants was similar to that of Armada and suggests that resistance in Armada is completely dominant. The observed F_2 segregation of 256(R):80(S) fit a 3:1 hypothesized ratio for one dominant gene (Table 2). However, segregation observed in the BC_1 population showed a significant departure from the expected 1R:1S ratio for one dominant gene and fit ($0.25<P<0.50$) a 3R:1S ratio expected for two dominant genes. This resulted from an excess of resistant plants in the BC_1 population.

Classification of F_3 lines resulted in 24 homozygous resistant, 61 segregating 3R:1S, and 15 homozygous susceptible lines (Table 3). This result deviated slightly ($P<0.05$) from the expected 1:2:1 F_2 genotypic ratio; however, among segregating families only monogenic ratios were observed which indicated that resistance in Armada is governed by one dominant gene.

Chancellor × SI5

Chancellor, SI5, and their F_1 had infection types of 9, 1, and 1 to 3, respectively. The observed segregation of 288(R+I):17(S) F_2 plants fit a 15:1 ratio, and indicated that SI5 has two dominant genes for resistance (Table 2). The segregation pattern of 3R:1S observed in the BC_1 population supported the two gene hypothesis. Classification of disease reaction in F_3 lines resulted in 37 homozygous resistant, 21 segregating 3R:1S, 34 segregating 15R:1S, and 8 homozygous susceptible lines (Table 3). These F_3 data fit a 7:4:4:1 F_2 genotypic ratio for two segregating genes. Results from each population were consistent and confirmed the presence of two genes for resistance in SI5. Contamination of isolate 127 was detected in this test, which resulted in increased virulence and failure to identify one of resistance genes in SI5. Results from crosses between SI5 and other lines also revealed

that SI5 has three genes (data presented in companion paper). Therefore, the F_2 population was retested using a pure culture of isolate 127 to elucidate the gene number in SI5. The observed segregation pattern of 448(R):5(S) F_2 plants fit ($0.25<P<0.50$) a 63:1 ratio and confirmed the three gene hypothesis.

Chancellor × Bulk PV63-6

Chancellor and Bulk PV63-6 had infection types of 9 and 1 to 3, respectively. Their F_1 plants had infection types of 4 to 5, which revealed that resistance in Bulk PV63-6 was partially dominant. Segregation among the F_2 progeny resulted in 144 resistant, 247 intermediate type, and 108 susceptible plants (Table 2). This observed segregation fit a 1R:2I:1S ratio, which is expected for the segregation of one partially dominant gene. The segregation of 36(I):40(S) plants in the BC_1 population confirmed the 1I:1S hypothesis for one resistance gene in Bulk PV63-6. Classification of F_3 lines resulted in 19 homozygous resistant lines, 55 lines segregating 3R:1S, and 26 homozygous susceptible lines (Table 3). This classification of F_3 lines supported a 1:2:1 F_2 genotypic ratio and provided further evidence that Bulk PV63-6 has one partially dominant gene for resistance.

Chancellor × VPM1

Infection types of 9 and 1 to 2, respectively, were observed for Chancellor and VPM1. The susceptible reaction of F_1 plants suggested that resistance in VPM1 was recessive in this case. Genetic analysis of the F_2 population comprised of 104 resistant or intermediate-type plants and 364 susceptible plants revealed that resistance in VPM1 is governed by a single recessive gene (Table 2). No data for a BC_1 population are available. The single recessive gene postulate was confirmed by the F_3 data for which 22 resistant, 46 segregating (1R:3S), and 25 susceptible lines were observed (Table 3). This data fit the expected 1:2:1 F_2 genotypic ratio.

Chancellor × ST1-25

The parent ST1-25 had an intermediate reaction type (IT = 4-5), and the F_1 reaction type (IT = 6-8) was close to that of Chancellor. In the F_2 population, 100 resistant plus intermediate and 281 susceptible plants were observed (Table 2). This F_2 segregation pattern fit a 1R+I:3S ratio for one recessive gene. No backcross data are available. Classification of F_3 lines resulted in 14 resistant, 44 segregating 1R:3S, and 42 susceptible lines (Table 3). An excess of susceptible families was observed and, therefore,

the F_3 data failed to fit the expected 1:2:1 F_2 genotypic ratio.

DISCUSSION

The parents evaluated in this genetic study were all resistant to *B. graminis* f. sp. *tritici* isolate 127, except for ST1-25 whose reaction was intermediate. Isolate 127, which had fewest genes for virulence among 18 *Blumeria graminis* f. sp. *tritici* isolates previously described by Leath and Heun (1990), was used in the current study in order to determine the putative number of resistance genes in the 10 parental lines. Intermediate disease reactions were observed among the progeny in almost every cross, which indicated that resistance was partially dominant in many cases.

Genetic analysis of populations derived from crosses between Chancellor and C39 revealed that C39 has three independent dominant genes for resistance. The resistance in A55-2, R107, OK75R3645, GO4779, and Bulk PV63-6 was expressed only partially in crosses with Chancellor. The hypothesized segregation ratios of 1R:2I:1S or 3R:1S in F_2 populations were accepted for all five crosses, and were confirmed upon evaluation of F_3 populations and F_2 genotypic ratios. Results of this study indicated that A55-2, R107, OK75R3645, GO4779, and Bulk PV63-6 each have one incompletely dominant gene for resistance to powdery mildew.

It is well known that Armada possesses the *Pm*4b resistance gene to powdery mildew (Bennett, 1984; McIntosh,

1988). Results from the current study confirmed the presence of one dominant gene for resistance in Armada based on analysis of the F2 population. However, an excess of resistant plants in the BC_1 population caused a deviation from the expected segregation ratio of 1R:1S. The BC_1 segregation for 56R:14S plants fit (P>0.25) a 3R:1S ratio, which suggested that Armada may have two genes for resistance. Because conflicting results were obtained from analysis of F_2 and BC_1 populations, 312 additional F_2 plants were tested. From this test, 219 resistant and 93 susceptible F_2 plants were observed, and this segregation fit (P=0.05) a 3R:1S ratio, which supports the premise that Armada has one dominant gene for resistance.

Bennett (1984) reported that VPM1 also has the resistance gene *Pm4b*. However, the mode of inheritance of the resistance gene in VPM1 was different from that in Armada. The disease reaction of F1 plants indicated that the gene in VPM1 behaves like a recessive gene while that of Armada is dominant. The recessive behavior of the VPM1 gene was confirmed in analysis of the F_2 population in which a 1R:3S segregation ratio was accepted. In analysis of resistance in VPM1, it was difficult to identify the homozygous resistant lines among 93 F3 families, because the disease reaction within these putative homozygous resistant lines varied considerably, unlike those

observed in F3 lines from other crosses. This indicated that the resistance in VPM1 was very unstable. While Armada and VPM1 both may possess *Pm4b,* the mode of inheritance differs for crosses with these parents. If the resistance genes in both parents are common, differences in genetic background may affect gene penetrance and expression. A possible explanation can be deduced from pedigree analysis of VPM1, which includes *Aegilops ventricosa* (Table 1; Bennett, 1984). Even though the mildew resistance gene (*Pm*4b) of VPM1 is not located in the D^v genome, which is known to contain a large chromosomal segment of *A. ventricosa*, the heterogeneous genetic constitution of VPM1 or the presence of modifying genes in this alien segment may affect the expression of the resistance gene in VPM1 compared to that observed in Armada.

Genetic analysis of populations derived from crosses between Chancellor and SI5 indicated that SI5 possesses two or likely three dominant genes for resistance. One of the resistance genes may be *Pm4b* derived from VPM, which is one of the parents of SI5 (Table 1). The other resistance gene(s) may have originated from the parent 'Prieur' because the other two parents ('Moisson' and US 60-43) do not have any known resistance genes (Zeller et. al., 1993b). ST1-25 had an intermediate reaction to powdery mildew, and one recessive gene for resistance was postulated based on segregation of the

F_2 population. Results from analysis of the F_3 population were inconclusive due to an excessive number of observed susceptible families. This may have resulted due to low penetrance of the gene and its low level of expression.

Results from this genetic study revealed that six of the ten parents each have a single partially to completely dominant gene; two parents each have a single recessive gene; and two parents each have three dominant genes for resistance to *Blumeria graminis* f. sp. *tritici* isolate 127. Among the 10 parents, it is possible that as few as three genes or as many as eleven different resistance genes are represented. Some of the resistance genes may be common in these parental lines; therefore, further genetic studies are required to determine the identity and number of unique resistance genes present in these lines. Resistance in all of the lines, except ST1-25, is currently effective to the prevalent *B. graminis* f. sp. *tritici* populations found in Virginia (authors, personal observation). Among the most widely used resistance genes, only *Pm4b* and *Pm17* are still completely effective in the mid-Atlantic and southeastern regions of the U.S.A. (S. Leath, personal communication); therefore, new sources or effective combinations of resistance to powdery mildew are needed to prevent disease losses.

Table 1. Origin of wheat parents and their infection types to *Blumeria graminis* f. sp. *tritici* isolate 127.

Parental line[†]	Origin	Infection Type[≠]
Chancellor	U.S.A.	9
C39	England	1
A55-2	England	1
R107	England	1
GO4779[§]	Greece	1-3
OK75R3645[¶]	U.S.A.	3
Armada[♯]	England	1-3
SI5[††]	France	1
Bulk PV63-6[##]	France	1-3
VPM1[§§]	France	1-2
ST1-25	Australia	4-5

[†]ST1-25 was selected from the 1982 International Winter Wheat Rust Nursery and all other parents came from the 1982 International Winter Wheat Mildew Nursery.

[≠]Based on the 0-9 scale of Moseman et al. (1984) where 0 = immune, 1 to 3 = resistant, 4 to 6 = moderately resistant, and 7 to 9 = susceptible.

[§] =Kenya C6042/Dux/2/Quaderna/3/Mara

[¶] =Cofen/Sturdy/2/Suwon 92/5/Heine Kolben 38/4/(II-54-45) Frontana/2/Kenya Farmer/Newthatch/3/Thatcher

[♯] =Tp118/2/Perdix/Hybrid 46/3/Capelle Desprez/Champlein/ 4/Viking/Tetrix/2/Tetrix/Jubilegem

[††] =VPM/Moisson/2/US 60-43/Prieur

[##] =Maris Huntsman/2/VPM/Moisson

[§§] =*Aegilops ventricosa/Triticum Persicum*/2/3*Marne

Table 2. Segregation ratios for seedling reaction of F_2 and BC_1 (Chancellor × F_1) populations, derived from crosses of the susceptible cultivar Chancellor (CC) with 10 resistant wheat lines, to *Blumeria graminis* f. sp. *tritici* isolate 127.

Cross	Popul-ation	Number of plants				Ratio Tested	Probability
		R†	R+I	I	S		
CC × C39	F_2	863			16	63:1	0.50-0.75
	BC_1	59			14	7:1	0.05-0.10
CC × A55-2	F_2	102		215	93	1:2:1	0.50-0.75
	BC_1			47	31	1:1	0.05-0.10
CC × R107	F_2	68		113	65	1:2:1	0.25-0.50
	BC_1			40	35	1:1	0.50-0.75
CC × GO4779	F_2		329		120	3:1	0.25-0.50
	BC_1			33	39	1:1	0.25-0.50
CC×Ok75R3645	F_2	138		292	147	1:2:1	0.50-0.75
	BC_1			26	29	1:1	0.50-0.75
CC × Armada	F_2	256			80	3:1	0.50-0.75
	BC_1	56			14	1:1	>0.05
CC × SI5	F_2		288		17	15:1	0.50-0.75
	BC_1		44		16	3:1	0.75-0.90
CC×Bulk PV63-6	F_2	144		247	108	1:2:1	0.05-0.10
	BC_1			36	40	1:1	0.50-0.75
CC × VPM1	F_2		104		364	1:3	0.10-0.25
CC × ST1-25	F_2		100		281	1:3	0.50-0.75

†Reaction type classes were R = resistant, I = intermediate, and S = susceptible.

Table 3. F_2 genotypic ratios derived from seedling reaction of F_3 families, from crosses between the susceptible cultivar Chancellor (CC) and 10 resistant wheat lines, to *Blumeria graminis* f. sp. *tritici* isolate 127.

	Number of F_3 families						
	Homo.	Segregating			Homo.	F_2	
Cross	R†	1gene‡	2gene	3gene	S§	ratio	Probability
CC × C39	62	11	17	10	0	37:6:12:8:1	0.50-0.75
CC × A55-2	25	51			21	1:2:1	0.25-0.50
CC × R107	25	52			24	1:2:1	0.90-0.95
CC × GO4779	23	49			28	1:2:1	0.10-0.25
CC × OK75R3645	19	56			25	1:2:1	0.25-0.50
CC × Armada	24	61			15	1:2:1	< 0.05
CC × SI5	37	21	34		8	7:4:4:1	0.10-0.25
CC × Bulk PV63-6	19	55			26	1:2:1	0.25-0.50
CC × VPM1	22	46			25	1:2:1	0.50-0.75
CC × ST1-25	14	44			42	1:2:1	< 0.05

† = Homozygous resistant.

‡ 3R:1S segregation observed for all crosses except CC × VPM1 and CC × ST1-25 which segregated 1R:3S.

§ = Homozygous susceptible.

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Chapter II

Identity of Resistance Genes

ABSTRACT

Eight of ten powdery mildew resistant wheat (*Triticum aestivum* L.) lines, genetically characterized in the previous study, were crossed with each other and to each of 13 host differential lines with known genes for resistance to powdery mildew, caused by *B. graminis* f. sp. *tritici* Em. Marchal. 300 to 800 F_2 seedlings were evaluated to isolate 127 of *B. graminis* f. sp. *tritici* to determine the relationship and putative identity of resistance genes in the eight lines. From results obtained for crosses between resistant parents, one common gene, *Pm4b,* was identified in C39, A55-2, R107, 'Armada', and SI5. The three genes in C39 and SI5 were identified as *Pm2*, 4b and 6 based on lack of segregation in crosses of these lines with the corresponding differentials. The resistance genes in OK75R3645 and GO4779 differ from each other and from those identified in the other lines. The resistance gene in OK75R3645 likely is an allele or closely linked to the *Pm3* locus. It is probable that the resistance gene in GO4779 is *Pm1,* as no segregation was observed in the cross with the differential line Axminster/8*CC(*Pm1*). A single recessive gene, *Pm8*, was postulated for ST1-25, whose disease reaction was intermediate to isolate 127.

INTRODUCTION

Powdery mildew caused by *Blumeria graminis* (DC.) E. O. Speer f. sp. *tritici* Em. Marchal is one of the most prevalent diseases of wheat (*Triticum aestivum L.*) in areas with a maritime or semi-continental climate and in many areas results in significant yield losses each year (Bennett, 1984; Bowen et al., 1991). Genetic resistance has provided the most effective and efficient means to manage powdery mildew. For more than 40 years, intensive research has been conducted to identify and incorporate new sources of powdery mildew resistance into commercial cultivars. During that time, extensive searches for new sources of powdery mildew resistance have resulted in the identification of only a few widely effective genes (Bennett, 1984). Lack of information on the identity of resistance genes present in cultivars and germplasm used in breeding programs hinders efficient use of the few resistance genes available. Therefore, identification and characterization of resistance in cultivars and germplasm is an important prerequisite for the effective deployment of resistance genes in developing genetically diverse cultivars with broad resistance.

Recently, information on the underlying resistance in many wheat cultivars has been reported and should be valuable to breeders for improving the systematic use of powdery mildew resistance genes (Hovmøller, 1989; Leath and Heun, 1990; Lutz et al., 1992; Zeller et al., 1993). Zeller et al. (1993)

screened 35 French wheat cultivars using 12 different *Blumeria graminis* f. sp. *tritici* isolates, and postulated the presence of six race-specific resistance genes (*Mlar*, *Pm2*, 4b, 5, 6, 8) and combinations of two genes in six cultivars. Resistance genes *Pm2*, 4b and 6, and 5, respectively, were the most common. Twenty-four Czechoslovakian wheat cultivars were assessed similarly and six major genes (*Mlk*, *Pm2*, 4b, 5, 6, 8) for resistance were identified (Lutz et al., 1992). Seven cultivars had two genes and one had three genes. The most common genes were *Pm4b*, 5 and 8. Leath and Heun (1990) evaluated 22 soft red winter wheats using 27 *Blumeria graminis* f. sp. *tritici* isolates. Eight cultivars did not have any known genes for resistance, and the genes *Pm3a*, 5, and 6 were identified in the remaining cultivars. Such studies are capable of postulating genes present in a larger number of lines than is feasible via genetic studies. However, inheritance studies provide more information on the genetic basis for resistance, such as estimates of actual gene number, mode of inheritance, and linkage and allelic relationships (Dorothee et al., 1991).

Powdery mildew resistance in 10 wheat lines, as discussed in the previous paper, is governed by one to three genes. However, in the previous study, it was not possible to determine whether the 10 parents possess known or unique genes for resistance or if they have genes in common. Therefore,

genetic analyses of crosses between each of the resistant parents and crosses with differential host lines with known powdery mildew resistance genes were conducted. The main objectives of the present study were: 1) to determine if the resistant parents have genes in common; 2) to confirm the previous estimates of gene number in resistant parents through the evaluation of their populations in which segregation occurs; and 3) to determine if the parents have known or unique genes for resistance.

MATERIALS AND METHODS

Genetic populations

Eight of the ten powdery mildew resistant wheat lines, genetically characterized in the previous study were crossed with each other. The resistant parents also were crossed to 13 host differential lines (provided by Dr. S. Leath, North Carolina State University) with known genes for powdery mildew resistance (Table 4). Ten F_1 seeds from each cross were planted in the field and the plants were harvested individually. Three plants from each cross, which produced the most F_2 seed, were selected for this study.

Greenhouse evaluation

Assessment of parents, F_2 progeny and differential lines for their reaction to *Blumeria graminis* f. sp. *tritici* isolate 127 was made using the same inoculation and evaluation methods as described in the previous study. For each cross, 10 seedlings of each parent and 300 to 800 F_2 seedlings were evaluated in the greenhouse. Data for F_2 plants derived from individual F_1 plants from the same cross were pooled only when homogeneous.

RESULTS

Infection types of the eight resistant wheat lines to isolate 127 varied from 0 to 5. Line ST1-25 was moderately resistant, and the other parents were resistant. Infection types of the 13 differential lines are presented in Table 4.

Genetic analysis of crosses between resistant parents

Progeny of the crosses between eight of the ten parents were evaluated to determine whether resistance genes in the parents differed or were common to each other (Table 5). Some crosses with Bulk PV63-6 and VPM1 were not made because these lines were reported to have the same gene (*Pm4b*) as 'Armada' (Bennett, 1984; personal communication).

No segregation among F_2 progeny was observed in any of the crosses between C39, A55-2, R107, Armada, and SI5, which indicated that these lines have at least one gene in common (Table 5). The common gene most likely is *Pm4b* because no segregation among F_2 progeny was observed in crosses between Armada and the other four lines. Segregation among F_2 progeny was observed in crosses of C39, A55-2, R107, Armada and SI5 with OK75R3645, GO4779 and ST1-25, and revealed that the resistance genes in OK75R3645, GO4779, and ST1-25 were different than *Pm4b* and the other genes in C39 and SI5.

Segregation of F_2 progeny also was observed in the crosses between GO4779, ST1-25 and OK75R3645, and indicated that they also have different genes for resistance.

In crosses where segregation was observed among F_2 progeny, expected ratios based on putative gene numbers were accepted in most cases. These results corroborate with the findings of the previous paper, in which it was postulated that C39 and SI5 have three genes and the remaining parents each have a single resistant gene. Six to eight different resistance genes may be represented in the 10 parents.

Genetic analysis of crosses between resistant parents and 13 differential lines

C39 × differential lines

Segregation in F_2 progeny was observed in crosses of C39 with differential lines which possess the genes *Pm1*, 3a, 3b, 3c, 5, 7, 8, and 17, indicating that the resistance genes in C39 and these lines are different (Table 6). The observed F_2 segregation patterns in these crosses confirmed that C39 has three genes for resistance. No segregation of F_2 was observed in crosses between C39 and differential lines containing *Pm2*, 4a, 6, 5+6, and 2+6. The lack of segregation in the cross between C39 and Khapli/8*CC(Pm4a) resulted from the allelic

relationship between Pm4a and one of resistance genes(Pm4b) in C39. The *Pm4b* allele is resistant to the prevalent *B. graminis* f. sp. *tritici* populations found in Virginia while *Pm4a* is susceptible. C39 and other lines for which *Pm4b* has been postulated are resistant to powdery mildew isolates capable of overcoming *Pm4a*; therefore, it can be deduced that they have *Pm4b*. Results of this study also indicated that the other two resistance genes in C39 must be *Pm2* and *Pm6*.

A55-2 × differential lines

Previously, it was postulated that A55-2 possesses *Pm4b* based on lack of segregation in the cross between A55-2 and Armada, which is known to have *Pm*4b (Table 5). This was confirmed in analysis of crosses between A55-2 and 13 differential lines (Table 7). In the crosses between A55-2 and 12 differential lines, observed segregating patterns in all cases fit the expected ratios. As expected, no susceptible plants were detected in the cross between A55-2 and Khapli/8*CC, which has the *Pm4a* allele.

R107 × differential lines

From results of the cross between R107 and Armada, it was deduced that the resistance gene in R107 was *Pm4b* (Table 5). This postulate was confirmed in the genetic analysis of R107 × differential crosses (Table 8). Segregation was observed in

most of the crosses between R107 and the differential lines as expected; however, segregation was not observed in two crosses due to small population sizes. In most cases, the observed segregation patterns fit the expected ratios and confirmed previous results which indicated that R107 has one gene for resistance. No segregation was observed in the cross between R107 and Khapli/8*CC indicating the presence of *Pm4b* in R107.

GO4779 × differential lines

There was no segregation among 793 F_2 plants from the cross between GO4779 and Axminster/8*CC (Table 9). This indicated that GO4779 possesses the *Pm1* resistance gene. The F_2 progeny of the other crosses segregated as expected, and analysis of segregation ratios confirmed the previous hypothesis that GO4779 has a single resistance gene.

OK75R3645 × differential lines

Only one susceptible plant was identified among 900 F_2 plants in the cross of OK75R3645 with Asosan/8*CC (Table 10), which indicated that the resistance gene in OK75R3645 is allelic to or closely linked to *Pm3a*. OK75R3645 is resistant to *B. graminis* f. sp. *tritici* isolates which have virulence for *Pm3a*; therefore, OK75R3645 must have a different allele or gene. Segregation in the crosses of OK75R3645 with Chul/8*CC

(*Pm3b*) and Sonora/8*CC (*Pm3c*) was not as expected, and in both crosses a 1R:1S ratio was observed. This also suggests that the gene in OK75R3645 is not inherited independently of the alleles at the *Pm3* locus. The observed segregation patterns in most crosses fit the postulated ratios and supported the premise that OK75R3645 has one resistance gene.

SI5 × differential lines

Two genes for resistance in SI5 were initially postulated in the previous paper. However, analysis of observed segregation patterns in the current study revealed that SI5 has three genes for resistance (Table 11). The contradiction of results for SI5 in these two studies was due to the contamination of isolate 127 in the previous study, which resulted in an increase in virulence. Therefore, F_2 progeny from the 'Chancellor' × SI5 cross were retested using a pure culture of isolate 127 to confirm the number of resistance genes present in SI5. The observed segregation pattern of 448R:5S plants fit ($0.25<P<0.50$) a 63:1 ratio and, therefore, verified that SI5 has three dominant genes.

In the current study, no segregation in the crosses of SI5 with Ulka/8*CC(*Pm2*), Armada(*Pm4b*), 'Coker747'(*Pm6*), and Tp114(*Pm2+6*) was observed, and indicated that the three resistance genes in SI5 are *Pm2, 4b, 6* (Table 11).

Unexpectedly, 12 susceptible plants were found in the cross between SI5 and Khapli/8*CC(*Pm*4a) for which segregation was not expected because both parents have resistant alleles at the *Pm*4 locus. The observed segregation pattern fit a 63R:1S ratio indicating that the selected differential plant used in the cross might be Chancellor. Three susceptible plants were observed among the F_2 progeny of the cross between SI5 and 'Coker 983' (*Pm*5+6), which was unexpected based on the premise that both parents have *Pm*6. To verify that SI5 has *Pm*6, 453 additional F_2 progeny from the cross between SI5 and Coker 747 were evaluated. As in the initial test, no segregation was observed; therefore, it seems likely that *Pm*6 is one of the three genes present in SI5.

ST1-25 × differential lines

The parent ST1-25 had an intermediate reaction (IT = 4-5) to isolate 127. In the cross between ST1-25 and 'Kavkaz'(*Pm*8), only four marginally susceptible F_2 plants (IT = 7) were found (Table 12). Because no highly susceptible plants were observed in this cross, it is likely that ST1-25 has *Pm*8. ST1-25 is susceptible to *Blumeria graminis* f. sp. *tritici* isolates that have virulence for *Pm*8, which supports the results found here. In a few crosses, an excess of susceptible F_2 plants was found, and the observed segregation patterns failed to fit the

expected ratios. This was observed for the crosses between ST1-25 and the susceptible differential lines Chul/8*CC (*Pm*3b), Hope/8*CC (*Pm*5), and Transec (*Pm*7). The observed segregation patterns in the remaining crosses conformed to the expected ratios, and confirmed the hypothesis that ST1-25 has a single recessive gene.

DISCUSSION

Gene numbers postulated in the previous study from analysis of crosses between 10 powdery mildew resistant parents and susceptible Chancellor were confirmed in the current genetic study in which F_2 progeny derived from resistant × resistant and resistant × differential line crosses were evaluated. Results obtained in the current study also were supported by those found by S. Leath (Unpublished results) in a preliminary study, in which the 10 resistant parents were evaluated using 18 different powdery mildew isolates to determine probable resistance gene(s). Identification of *Pm4b* in A55-2, R107, Armada, Bulk PV63-6, and VPM1 was confirmed in both studies. The preliminary study failed to identify the resistance genes in C39 and SI5, probably due to the presence of multiple genes in these lines. The genes *Pm1* and *Pm8*, respectively, were postulated for GO4779 and ST1-25 in both studies. The identity of the resistance gene in OK75R3645 was not determined in the preliminary study due to the inability of these isolates to differentiate alleles at the *Pm3* locus.

In the current genetic study, *Pm*4b was the most common resistance gene found among the parents and was identified in Armada, C39, A55-2, R107 and SI5. This gene is still effective in the United States, yet it has not been used in commercial

cultivars (S. Leath, personal communication).

Three genes, *Pm*2, 4b, and 6 were identified in C39 and SI5. These genes have been used frequently in breeding programs in the United Kingdom and France (Bennett, 1984; Zeller et al., 1993). From this study and other recent reports (Hovmøller, 1989; Lutz et al, 1992; Zeller et al, 1993), it appears that there is insufficient genetic diversity among European cultivars for powdery mildew resistance.

In the current genetic study, the powdery mildew resistance gene in OK75R3645 was shown to be allelic or closely linked to *Pm*3a. Segregation ratios of 1R:1S were observed in the crosses of OK75R3645 with Chul/8*CC (*Pm*3b) and Sonora/8*CC (*Pm*3c). These observed segregation patterns were unexpected; however, when considering a possible linkage relationship between the gene in OK75R3645 with the *Pm*3 locus, it is possible that there was strong interaction between genes which resulted in these deviated segregation patterns. Another unexpected segregation pattern was found in the cross between OK75R3645 and 'Amigo' and may have resulted from a linkage relationship between the resistance genes in these lines. The resistance gene *Pm*17 in Amigo is located on the same chromosome as the *Pm*3 locus (Lowry et al, 1984). The gene *Pm*3a is located on chromosome 1AS (Briggle and Sears, 1966), and *Pm*17 which is on the rye chromosome 1RS was translocated to 1AS (Heun et al, 1990). In the current genetic study, only

six susceptible F_2 plants were observed in a population of 718 for the cross between OK75R3645 and Amigo; therefore, it is evident that a linkage relationship exists between these loci as proposed by Lowry et al. (1984). Partial pairing between the homoeologous chromosomes, 1AS and 1RS, could result in recombination between the two loci, which would result in a few susceptible recombinants.

The resistance gene in GO4779 likely is *Pm1* or a closely linked gene since no segregation was observed in the cross of GO4779 with Axminster/8*CC(*Pm1*). While *Pm1* also was postulated as the resistance gene in GO4779 by Jeyandran (1984) and by Leath (unpublished results) in a preliminary study, disease reaction varies somewhat between GO4779 and Axminster/8*CC to *Blumeria graminis* f. sp. *tritici* isolates; therefore, further studies are required to determine the exact relationship between these genes. GO4779 may have additional genes, such as *Pm*9 (Dorothee et al., 1991), that modify the expression of *Pm*1 in this line.

In summary, a total of six resistance genes conferring resistance to *Blumeria graminis* f. sp. *tritici* isolate 127 were found in the 10 resistant wheat lines. Some of the resistance genes or their alleles already have been used in Virginia wheat cultivars; for example, *Pm*1 in 'Wakefield' (Starling et al., 1991) and *Pm*3a in 'Tyler' and 'Saluda'

(Starling et al., 1984; 1986). Resistance genes *Pm*5 and *Pm*6 also have been used in the U.S.A. and are present in cultivars which were released in the eastern U.S.A. (Leath and Heun, 1990). However, among the most widely used resistance genes, only *Pm*4b and *Pm*17 are individually effective. Identification of specific genes in cultivars and germplasm and the knowledge of effective genes and gene combinations is needed to effectively utilize the limited number of resistance genes available to breeders.

Table 4. Differential wheat lines with known genes for powdery mildew resistance and their reaction to *Blumeria graminis* f. sp. *tritici* isolate 127.

Line	Accession number	Resistance gene(s)	Infection type[†]
Axminster/8*CC[‡]	CI14114	*Pm1*	1
Ulka/8*CC	CI14118	*Pm2*	1-2
Asosan/8*CC	CI14120	*Pm3a*	1
Chul/8*CC	CI14121	*Pm3b*	9
Sonora/8*CC	CI14122	*Pm3c*	9
Khapli/8*CC	CI14123	*Pm4a*	1
Hope/8*CC	CI14125	*Pm5(=Mli)*	9
Coker747	CI17923	*Pm6*	3-4
Coker983	none	*Pm5+6*	1-3
Tp114	PI405718	*Pm2+6*	...
Transec	CI14189	*Pm7*	9
Kavkaz	PI361879	*Pm8*	3-5
Amigo	CI17609	*Pm17*	1

[†] Reaction as described by Moseman et al.(1984) were 0 = immune; 1-3 = resistant; 4-6 = moderately resistant; and 7-9 = susceptible. [‡] Backcrossed eight times to 'Chancellor'.

Table 5. Uniqueness of resistance genes in eight wheat lines based on observed segregation patterns of their F_2 progeny, derived from a partial diallel, to *Blumeria graminis* f. sp. *tritici* isolate 127.

Line	C39 (3)[†]	A55-2 (1)	R107 (1)	Go4779 (1)	OK75R-3645(1)	Armada (1)	SI5 (3)	ST1-25 (1)
C39 (3)	*	No[‡] seg	No seg	255:1[§] 0.10-0.25[¶]	255:1 0.25-0.50	No seg	No seg	253:3 0.10-0.25
A55-2 (1)		*	No seg	15:1 0.10-0.25	15:1 0.75-0.90	No seg	No seg	13:3 0.05-0.10
R107 (1)			*	15:1 0.50-0.75	15:1 <0.05	No seg	No seg	13:3 0.50-0.75
GO4779 (1)				*	15:1 0.25-0.50	15:1 0.25-0.50	255:1 0.25-0.50	13:3 0.05-0.10
OK75R-3645(1)					*	15:1 <0.05	255:1 <0.05	13:3 0.50-0.75
Armada (1)						*	No seg	13:3 0.10-0.25
SI5 (3)							*	253:3 <0.05
ST1-25 (1)								*

[†]Putative gene number postulated in previous paper.

[‡]No segregation among F_2 progeny observed, indicating that the parents have at least one gene in common.

[§]Segregation ratios tested. [¶]Probability from Chi-square.

Table 6. Reaction of F_2 progeny from crosses of C39 with 13 differential lines to *Blumeria graminis* f. sp. *tritici* isolate 127.

Cross C39[†] × differential	Observed R[‡]	S	Ratio tested	P	Putative gene no[§]
Axminster/8*CC (Pm1)	547	4	255:1	0.10-0.25	4
Ulka/8*CC(Pm2)	713	0	-----	------	common[¶]
Asosan/8*CC(Pm3a)	612	1	255:1	0.25-0.50	4
Chul/8*CC(Pm3b)	642	10	63:1	>0.995	3
Sonora/8*CC(Pm3c)	655	7	63:1	0.25-0.50	3
Khapli/8*CC(Pm4a)	772	0	-----	------	allele[#]
Hope/8*CC(Pm5)	506	9	63:1	0.50-0.75	3
Coker747(Pm6)	659	1	-----	------	common
Coker983(Pm5+6)	772	0	-----	------	common
Tp114(Pm2+6)	640	0	-----	------	common
Transec(Pm7)	603	11	63:1	0.50-0.75	3
Kavkaz(Pm8)	714	12	253:3	0.10-0.25	4
Amigo(Pm17)	811	5	255:1	0.25-0.50	4

[†]The putative gene number for C39 is three.

[‡]R = resistant and S = susceptible progeny.

[§]Suggested number of effective genes in each cross.

[¶]No segregation among F_2 progeny indicating that the parents have at least one gene in common.

[#]One of the resistance genes in C39 is Pm4b.

Table 7. Reaction of F_2 progeny from crosses of A55-2 with 13 differential lines to *Blumeria graminis* f. sp. *tritici* isolate 127.

Cross A55-2[†] × differential	Observed R[‡]	S	Ratio tested	P	Putative gene no[§]
Axminster/8*CC (Pm1)	527	35	15:1	> 0.99	2
Ulka/8*CC(Pm2)	594	37	15:1	0.50-0.75	2
Asosan/8*CC(Pm3a)	553	37	15:1	> 0.99	2
Chul/8*CC(Pm3b)	307	101	3:1	0.50-0.75	1
Sonora/8*CC(Pm3c)	301	112	3:1	0.25-0.50	1
Khapli/8*CC(Pm4a)	713	0	----	------	allele[¶]
Hope/8*CC(Pm5)	330	101	3:1	0.25-0.50	1
Coker747(Pm6)	303	16	15:1	0.25-0.50	2
Coker983(Pm5+6)	470	25	15:1	0.25-0.50	2
Tp114(Pm2+6)	365	2	63:1	0.10-0.25	3
Transec(Pm7)	146	44	3:1	0.50-0.75	1
Kavkaz(Pm8)	515	28	15:1	0.25-0.50	2
Amigo(Pm17)	593	33	15:1	0.25-0.50	2

[†]The putative gene number for A55-2 is one.

[‡]R = resistant and S = susceptible progeny.

[§]Suggested number of effective genes in each cross.

[¶]One of the resistance genes in A55-2 is Pm4b.

Table 8. Reaction of F_2 progeny from crosses of R107 with 13 differential lines to *Blumeria graminis* f. sp. *tritici* isolate 127.

Cross R107[†] × differential	Observed R[‡]	S	Ratio tested	P	Putative gene no[§]
Axminster/8*CC (Pm1)	533	31	15:1	0.25-0.50	2
Ulka/8*CC(Pm2)	583	31	15:1	0.10-0.25	2
Asosan/8*CC(Pm3a)	205	10	15:1	0.25-0.50	2
Chul/8*CC(Pm3b)	358	124	3:1	0.50-0.75	1
Sonora/8*CC(Pm3c)	398	100	3:1	< 0.05	1
Khapli/8*CC(Pm4a)	466	0	---	-----	allele[¶]
Hope/8*CC(Pm5)	248	97	3:1	0.10-0.25	1
Coker747(Pm6)	64	0	15:1	< 0.05	2
Coker983(Pm5+6)	309	13	15:1	0.50-0.75	2
Tp114(Pm2+6)	30	0	63:1	0.25-0.50	3
Transec(Pm7)	461	131	3:1	0.10-0.25	1
Kavkaz(Pm8)	180	16	15:1	0.25-0.50	2
Amigo(Pm17)	551	26	15:1	0.10-0.25	2

[†]The putative gene number for R107 is one.

[‡]R = resistant and S = susceptible progeny.

[§]Suggested number of effective genes in each cross.

[¶]One of the resistance genes in R107 is Pm4b.

Table 9. Reaction of F_2 progeny from crosses of GO4779 with 13 differential lines to *Blumeria graminis* f. sp. *tritici* isolate 127.

Cross GO4779[†] × differential	Observed R[‡]	S	Ratio tested	P	Putative gene no[§]
Axminster/8*CC (Pm1)	793	0	----	-----	common[¶]
Ulka/8*CC(Pm2)	571	38	15:1	> 0.99	2
Asosan/8*CC(Pm3a	554	46	15:1	0.10-0.25	2
Chul/8*CC(Pm3b)	503	184	3:1	0.25-0.50	1
Sonora/8*CC(Pm3c	436	142	3:1	0.75-0.90	1
Khapli/8*CC(Pm4a	324	20	15:1	0.50-0.75	2
Hope/8*CC(Pm5)	389	127	3:1	0.75-0.90	1
Coker747(Pm6)	305	27	15:1	0.10-0.25	2
Coker983(Pm5+6)	300	25	15:1	0.25-0.50	2
Tp114(Pm2+6)	56	1	63:1	0.90-0.95	3
Transec(Pm7)	312	114	3:1	0.25-0.50	1
Kavkaz(Pm8)	309	93	13:3	< 0.05	2
Amigo(Pm17)	590	28	15:1	0.05-0.10	2

[†]The putative gene number for GO4779 is one.

[‡]R = resistant and S = susceptible progeny.

[§]Suggested number of effective genes in each cross.

[¶]No segregation among F_2 progeny indicating that the parents have at least one gene in common.

Table 10. Reaction of F_2 progeny from crosses of OK75R3645 with 13 differential lines to *Blumeria graminis* f. sp. *tritici* isolate 127.

Cross OK75R3645[†] × differential	Observed R[‡]	S	Ratio tested	P	Putative gene no[§]
Axminster/8*CC (Pm1)	683	32	15:1	0.05-0.10	2
Ulka/8*CC(Pm2)	662	40	15:1	0.50-0.75	2
Asosan/8*CC(Pm3a)	899	1	----	-----	allele[¶]
Chul/8*CC(Pm3b)	319	315	3:1	< 0.05	1
Sonora/8*CC(Pm3c)	290	274	3:1	< 0.05	1
Khapli/8*CC(Pm4a)	488	33	15:1	0.90-0.95	2
Hope/8*CC(Pm5)	355	132	3:1	0.25-0.50	1
Coker747(Pm6)	542	34	15:1	0.50-0.75	2
Coker983(Pm5+6)	779	32	15:1	< 0.05	2
Tp114(Pm2+6)	619	5	63:1	0.10-0.25	3
Transec(Pm7)	374	110	3:1	0.10-0.25	1
Kavkaz(Pm8)	444	99	13:3	0.75-0.90	2
Amigo(Pm17)	712	6	---	-----	2

[†]The putative gene number for OK75R3645 is one.

[‡]R = resistant and S = susceptible progeny.

[§]Suggested number of effective genes in each cross.

[¶]Limited segregation among F_2 progeny indicating that the resistance genes in the parents are the same or closely linked.

Table 11. Reaction of F_2 progeny from crosses of SI5 with 13 differential lines to *Blumeria graminis* f. sp. *tritici* isolate 127.

Cross SI5[†] × differential	Observed R[‡]	S	Ratio tested	P	Putative gene no[§]
Axminster/8*CC (Pm1)	593	2	255:1	0.75-0.90	4
Ulka/8*CC(Pm2)	619	0	----	-----	common[¶]
Asosan/8*CC(Pm3a)	651	3	255:1	0.75-0.90	4
Chul/8*CC(Pm3b)	583	6	63:1	0.25-0.50	3
Sonora/8*CC(Pm3c)	578	9	63:1	0.95	3
Khapli/8*CC(Pm4a)	511	12	63:1	0.10-0.25	3
Hope/8*CC(Pm5)	557	12	63:1	0.25-0.50	3
Coker747(Pm6)	582	0	----	-----	common
Coker983(Pm5+6)	614	3	255:1	0.50-0.75	4
Tp114(Pm2+6)	431	0	----	-----	common
Transec(Pm7)	280	5	63:1	0.75-0.90	3
Kavkaz(Pm8)	644	1	255:1	0.25-0.50	4
Amigo(Pm17)	591	1	255:1	0.25-0.50	4

[†]The putative gene number for SI5 is three.

[‡]R = resistant and S = susceptible progeny.

[§]Suggested number of effective genes in each cross.

[¶]No segregation among F_2 progeny indicating that the parents have at least one gene in common.

Table 12. Reaction of F_2 progeny from crosses of ST1-25 with 13 differential lines to *Blumeria graminis* f. sp. *tritici* isolate 127.

Cross ST1-25[†] × differential	Observed R[‡]	S	Ratio tested	P	Putative gene no[§]
Axminster/8*CC (Pm1)	409	96	13:3	0.75-0.90	2
Ulka/8*CC(Pm2)	322	81	13:3	0.25-0.50	2
Asosan/8*CC(Pm3)	432	88	13:3	0.25-0.50	2
Chul/8*CC(Pm3b)	40	181	1:3	< 0.05	1
Sonora/8*CC(Pm3c)	10	56	1:3	0.05-0.10	1
Khapli/8*CC(Pm4a)	303	63	13:3	0.25-0.50	2
Hope/8*CC(Pm5)	16	296	1:3	< 0.05	1
Coker747(Pm6)	169	31	13:3	0.10-0.25	2
Coker983(Pm5+6)	79	12	13:3	0.10-0.25	2
Tp114(Pm2+6)	9	1	61:3	0.25-0.50	3
Transec(Pm7)	93	456	1:3	< 0.05	1
Kavkaz(Pm8)	423	4[¶]	---	-----	common
Amigo(Pm17)	631	44	15:1	0.75-0.90	2

[†]The putative gene number for ST1-25 is one.

[‡]R = resistant and S = susceptible progeny.

[§]Suggested number of effective genes in each cross.

[¶]The four plants were only marginally susceptible (IT = 7) and no plants with infection type 9 were observed; therefore, the parents may have the same gene.

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Appendix A. Disease reaction of F3 families from cross between Chancellor and C39 to Blumeria graminis f. sp. tritici isolate 127.

NO	IT1+2	IT3	IT4	IT5	IT6	IT7	IT8	IT9	TOTAL	OR	OS	ER	ES	X2	NOTE
1	54								54	54.00	0.00	40.50	13.50	18	R
2	54								54	54.00	0.00	50.63	3.38	3.6	R
3	55								55	55.00	0.00	41.25	13.75	18.33333	R
4	39				3	7	3	8	60	42.00	18.00	45.00	15.00	0.8	1 SEG
5	55								55	55.00	0.00	51.56	3.44	3.666667	R
6	45		1		1		2	9	58	47.00	11.00	43.50	14.50	1.126437	1 SEG
7	51								51	51.00	0.00	47.81	3.19	3.4	R
8	50								50	50.00	0.00	46.88	3.13	3.333333	R
9	52								52	52.00	0.00	48.75	3.25	3.466667	R
10	54								54	54.00	0.00	50.63	3.38	3.6	R
11	53								53	53.00	0.00	49.69	3.31	3.533333	R
12	54								54	54.00	0.00	50.63	3.38	3.6	R
13	41					1		2	44	41.00	3.00	41.25	2.75	0.024242	2 SEG
14	54								54	54.00	0.00	40.50	13.50	18	R
15	55		2				1	3	61	57.00	4.00	57.19	3.81	0.009836	2 SEG
16	56					2	1		59	56.00	3.00	55.31	3.69	0.136723	2 SEG
17	49				1	1	2	1	54	50.00	4.00	50.63	3.38	0.123457	2 SEG
18	51		1					1	53	52.00	1.00	52.17	0.83	0.036238	3 SEG
19	48							2	50	48.00	2.00	46.88	3.13	0.432	2 SEG
20	53								53	53.00	0.00	49.69	3.31	3.533333	R
21	53					1			54	53.00	1.00	53.16	0.84	0.029394	3 SEG
22	54								54	54.00	0.00	50.63	3.38	3.6	R
23	52								52	52.00	0.00	48.75	3.25	3.466667	R
24	51								51	51.00	0.00	47.81	3.19	3.4	R
25	44		2		1	3	3	2	55	47.00	8.00	41.25	13.75	3.206061	1 SEG
26	55					1			56	55.00	1.00	55.13	0.88	0.018141	3 SEG
27	54								54	54.00	0.00	50.63	3.38	3.6	R
28	51								51	51.00	0.00	47.81	3.19	3.4	R
29	54								54	54.00	0.00	50.63	3.38	3.6	R
30	52								52	52.00	0.00	48.75	3.25	3.466667	R
31	52								52	52.00	0.00	48.75	3.25	3.466667	R
32	48				1				49	49.00	0.00	48.23	0.77	0.777778	3 SEG
33	53								53	53.00	0.00	49.69	3.31	3.533333	R
34	46		1		1				48	48.00	0.00	47.25	0.75	0.761905	3 SEG
35	56								56	56.00	0.00	52.50	3.50	3.733333	R
36	49				1	6	2	5	63	50.00	13.00	47.25	15.75	0.640212	1 SEG
37	52								52	52.00	0.00	48.75	3.25	3.466667	R
38	50		1					1	52	51.00	1.00	51.19	0.81	0.043956	3 SEG
39	52								52	52.00	0.00	48.75	3.25	3.466667	R
40	52		1						53	53.00	0.00	49.69	3.31	3.533333	R
41	53						1	3	57	53.00	4.00	53.44	3.56	0.05731	2 SEG
42	54		1						55	55.00	0.00	51.56	3.44	3.666667	R
43	55								55	55.00	0.00	51.56	3.44	3.666667	R
44	56								56	56.00	0.00	52.50	3.50	3.733333	R
45	57					1	2		60	57.00	3.00	56.25	3.75	0.16	2 SEG
46	52								52	52.00	0.00	48.75	3.25	3.466667	R
47	48		1			1	1		51	49.00	2.00	50.20	0.80	1.845316	3 SEG
48	48		2		1			4	55	51.00	4.00	51.56	3.44	0.098182	2 SEG
49	72					1			73	72.00	1.00	71.86	1.14	0.017613	3 SEG
50	54								54	54.00	0.00	50.63	3.38	3.6	R
51	50								50	50.00	0.00	46.88	3.13	3.333333	R

Appendix A. Continued

NO	IT1+2	IT3	IT4	IT5	IT6	IT7	IT8	IT9	TOTAL	OR	OS	ER	ES	X2	NOTE
52	52								52	52.00	0.00	48.75	3.25	3.466667	R
53	55		1				2	1	59	56.00	3.00	55.31	3.69	0.136723	2 SEG
54	51								51	51.00	0.00	47.81	3.19	3.4	R
55	57								57	57.00	0.00	53.44	3.56	3.8	R
56	53					1	1	6	61	53.00	8.00	45.75	15.25	4.595628	1 SEG
57	63		2					1	66	65.00	1.00	64.97	1.03	0.000962	3 SEG
58	64		1						65	65.00	0.00	60.94	4.06	4.333333	R
59	55		2						57	57.00	0.00	53.44	3.56	3.8	R
60	54								54	54.00	0.00	50.63	3.38	3.6	R
61	41				1	2	3	15	62	42.00	20.00	46.50	15.50	1.741935	1 SEG
62	56		3						59	59.00	0.00	55.31	3.69	3.933333	R
63	57					1	1	1	60	57.00	3.00	56.25	3.75	0.16	2 SEG
64	63		1						64	64.00	0.00	60.00	4.00	4.266667	R
65	53								53	53.00	0.00	49.69	3.31	3.533333	R
66	58		1						59	59.00	0.00	55.31	3.69	3.933333	R
67	38		3			1	5	9	56	41.00	15.00	42.00	14.00	0.095238	1 SEG
68	55								55	55.00	0.00	51.56	3.44	3.666667	R
69	56								56	56.00	0.00	52.50	3.50	3.733333	R
70	52		1					4	57	53.00	4.00	53.44	3.56	0.05731	2 SEG
71	53								53	53.00	0.00	49.69	3.31	3.533333	R
72	52								52	52.00	0.00	48.75	3.25	3.466667	R
73	55								55	55.00	0.00	51.56	3.44	3.666667	R
74	52								52	52.00	0.00	48.75	3.25	3.466667	R
75	52		2	1					55	55.00	0.00	51.56	3.44	3.666667	R
76	68		1	1	1			3	74	71.00	3.00	69.38	4.63	0.609009	2 SEG
77	51			3	1		1	3	59	55.00	4.00	55.31	3.69	0.028249	2 SEG
78	57		3		1	2	1	2	66	61.00	5.00	61.88	4.13	0.19798	2 SEG
79	54								54	54.00	0.00	50.63	3.38	3.6	R
80	50								50	50.00	0.00	46.88	3.13	3.333333	R
81	39		11			2	3	10	65	50.00	15.00	48.75	16.25	0.128205	1 SEG
82	51								51	51.00	0.00	47.81	3.19	3.4	R
83	26		23	4	3				56	56.00	0.00	52.50	3.50	3.733333	2 SEG
84	48		2			4	1	13	68	50.00	18.00	51.00	17.00	0.078431	1 SEG
85	56		25	1					82	82.00	0.00	76.88	5.13	5.466667	R
86	53								53	53.00	0.00	49.69	3.31	3.533333	R
87	52								52	52.00	0.00	48.75	3.25	3.466667	R
88	62								62	62.00	0.00	58.13	3.88	4.133333	R
89	62		3	1		2			68	66.00	2.00	66.94	1.06	0.840336	3 SEG
90	51					2	4	1	58	51.00	7.00	43.50	14.50	5.172414	2 SEG
91	62		1					4	67	63.00	4.00	62.81	4.19	0.008955	2 SEG
92	52								52	52.00	0.00	48.75	3.25	3.466667	R
93	59		2						61	61.00	0.00	57.19	3.81	4.066667	R
94	52		8	2					62	62.00	0.00	58.13	3.88	4.133333	R
95	57		3	1					61	61.00	0.00	57.19	3.81	4.066667	R
96	52								52	52.00	0.00	48.75	3.25	3.466667	R
97	26		10	7	4	3		15	65	47.00	18.00	48.75	16.25	0.251282	1 SEG
98	53		1						54	54.00	0.00	50.63	3.38	3.6	R
99	52								52	52.00	0.00	48.75	3.25	3.466667	R
100	49		2	1		3		6	61	52.00	9.00	45.75	15.25	3.415301	1 SEG

Appendix B. Disease reaction of F3 families from cross between Chancellor and A55-2 to Blumeria graminis f. sp. tritici isolate 127.

NO	IT1+2	IT3	IT4	IT5	IT6	IT7	IT8	IT9	TOTAL	OR	OS	ER	ES	X2	NOTE
1	23		3	5	8	18	8	3	68	39.00	29.00	51.00	17.00	11.29412	1 SEG
2	27								27	27.00	0.00	25.31	1.69	1.8	R
3	54								54	54.00	0.00	40.50	13.50	18	R
4	50		13	12	3	13	3	4	98	78.00	20.00	73.50	24.50	1.102041	1 SEG
5	56								56	56.00	0.00	52.50	3.50	3.733333	R
6	55								55	55.00	0.00	51.56	3.44	3.666667	R
7	35		13	11	11	10	5		85	70.00	15.00	63.75	21.25	2.45098	1 SEG
8	56								56	56.00	0.00	52.50	3.50	3.733333	R
9					1	26	16	22	65	1.00	64.00	60.94	4.06	943.2626	S
10	36		11	9	7	14	2	3	82	63.00	19.00	61.50	20.50	0.146341	1 SEG
11	20		9	6	5	21	5	17	83	40.00	43.00	77.81	5.19	293.996	
12	42		17	2	7	12	8	8	96	68.00	28.00	72.00	24.00	0.888889	1 SEG
13	75								75	75.00	0.00	70.31	4.69	5	R
14	58		10	4	7	12	4		95	79.00	16.00	71.25	23.75	3.37193	1 SEG
15	62		1						63	63.00	0.00	59.06	3.94	4.2	R
16				1	3	22	12	30	68	4.00	64.00	63.75	4.25	896.0157	S
17	26		7	7	14	15	7	17	93	54.00	39.00	69.75	23.25	14.22581	1 SEG
18	52		10	3	5	15	4	1	90	70.00	20.00	67.50	22.50	0.37037	1 SEG
19	46		17	10	7	11	8	10	109	80.00	29.00	81.75	27.25	0.149847	1 SEG
20	27		22	18	15	6	7	5	100	82.00	18.00	75.00	25.00	2.613333	1 SEG
21				3	1	20	19	24	67	4.00	63.00	62.81	4.19	881.0756	S
22	22		7	8	16	20	6	16	95	53.00	42.00	89.06	5.94	233.6344	
23	17		8	5	18	31	8	9	96	48.00	48.00	90.00	6.00	313.6	
24	22		3	9	13	36	1	14	98	47.00	51.00	91.88	6.13	350.6966	
25	21		11	3	5	13	2	3	58	40.00	18.00	43.50	14.50	1.126437	1 SEG
26	51		8	6	13	10	2	4	94	78.00	16.00	70.50	23.50	3.191489	1 SEG
27	53		2	1					56	56.00	0.00	52.50	3.50	3.733333	R
28						12	4	49	65	0.00	65.00	60.94	4.06	975	S
29	57		1						58	58.00	0.00	54.38	3.63	3.866667	R
30					2	22	7	33	64	2.00	62.00	60.00	4.00	897.0667	S
31	30		17	8	3	10	4		72	58.00	14.00	54.00	18.00	1.185185	1 SEG
32	55		1		1				57	57.00	0.00	53.44	3.56	3.8	R
33	48		5	6	2	11	3		75	61.00	14.00	56.25	18.75	1.604444	1 SEG
34	60		1						61	61.00	0.00	57.19	3.81	4.066667	R
35	24		14	6	11	9	3	5	72	55.00	17.00	54.00	18.00	0.074074	1 SEG
36	30		10	7	12	16	2	7	84	59.00	25.00	63.00	21.00	1.015873	1 SEG
37	58								58	58.00	0.00	54.38	3.63	3.866667	R
38						7	6	46	59	0.00	59.00	55.31	3.69	885	S
39	20		5	9	12	25	4	7	82	46.00	36.00	76.88	5.13	198.4033	
40	59								59	59.00	0.00	55.31	3.69	3.933333	R
41						17	10	36	63	0.00	63.00	59.06	3.94	945	S
42	30		8	8	22	21	5	4	98	68.00	30.00	73.50	24.50	1.646259	1 SEG
43						10	7	45	62	0.00	62.00	58.13	3.88	930	S
44						6	3	47	56	0.00	56.00	52.50	3.50	840	S
45			1			19	3	31	54	1.00	53.00	50.63	3.38	778.316	S
46	25		8	12	12	25	1	11	94	57.00	37.00	70.50	23.50	10.34043	1 SEG
47	43		6	8	5	14	2	9	87	62.00	25.00	65.25	21.75	0.64751	1 SEG
48						7	2	46	55	0.00	55.00	51.56	3.44	825	S
49	56		9	1	6	14	1	3	90	72.00	18.00	67.50	22.50	1.2	1 SEG
50					3	12	5	32	52	3.00	49.00	48.75	3.25	686.9538	S
51	48		5	4	7	7	4	1	76	64.00	12.00	57.00	19.00	3.438596	1 SEG

Appendix B. Continued

NO	IT1+2	IT3	IT4	IT5	IT6	IT7	IT8	IT9	TOTAL	OR	OS	ER	ES	X2	NOTE
52	51								51	51.00	0.00	47.81	3.19	3.4	R
53	35		8	12	19	18	3	3	98	74.00	24.00	73.50	24.50	0.013605	1 SEG
54	28		8	10	6	9	2	2	65	52.00	13.00	48.75	16.25	0.866667	1 SEG
55	34		10	8	8	11	1	5	77	60.00	17.00	57.75	19.25	0.350649	1 SEG
56	47		8	1	3	11	1	2	73	59.00	14.00	54.75	18.25	1.319635	1 SEG
57	43		7	4	3	10	1	1	69	57.00	12.00	51.75	17.25	2.130435	1 SEG
58	35		11	4	10	8		2	70	60.00	10.00	52.50	17.50	4.285714	1 SEG
59	53								53	53.00	0.00	49.69	3.31	3.533333	R
60	51								51	51.00	0.00	47.81	3.19	3.4	R
61						21	4	26	51	0.00	51.00	47.81	3.19	765	S
62	11		9	5	17	18	1	11	72	42.00	30.00	54.00	18.00	10.66667	1 SEG
63	53		11	4	1	12	1	7	89	69.00	20.00	66.75	22.25	0.303371	1 SEG
64	52								52	52.00	0.00	48.75	3.25	3.466667	R
65						4	2	48	54	0.00	54.00	50.63	3.38	810	S
66	24		15	6	11	12	1	2	71	56.00	15.00	53.25	17.75	0.568075	1 SEG
67	51		11	7	5	8			82	74.00	8.00	76.88	5.13	1.720325	
68	48		10	3	5	16	2	7	91	66.00	25.00	68.25	22.75	0.296703	1 SEG
69					2	23	2	31	58	2.00	56.00	54.38	3.63	807.177	S
70	51			2					53	53.00	0.00	49.69	3.31	3.533333	R
71	80		8	6	7	7		1	109	101.00	8.00	102.19	6.81	0.220795	
72	47		8	2	4	12	2	2	77	61.00	16.00	57.75	19.25	0.731602	1 SEG
73	53		2	1					56	56.00	0.00	52.50	3.50	3.733333	R
74					4	23	4	21	52	4.00	48.00	48.75	3.25	657.2513	S
75	56								56	56.00	0.00	52.50	3.50	3.733333	R
76	45		13	4	4	14	2	8	90	66.00	24.00	67.50	22.50	0.133333	1 SEG
77						11		42	53	0.00	53.00	49.69	3.31	795	S
78					1	20	6	25	52	1.00	51.00	48.75	3.25	748.3282	S
79	43		6	6	2	11	2	2	72	57.00	15.00	54.00	18.00	0.666667	1 SEG
80	44		7	8	7	10	3	5	84	66.00	18.00	63.00	21.00	0.571429	1 SEG
81	48		9	3	7	22	5	4	98	67.00	31.00	73.50	24.50	2.29932	1 SEG
82	35		10	10	10	11	4	8	88	65.00	23.00	66.00	22.00	0.060606	1 SEG
83	37		4	4	4	13	2	3	67	49.00	18.00	50.25	16.75	0.124378	1 SEG
84			1		3	24	8	18	54	4.00	50.00	50.63	3.38	687.0568	S
85	52								52	52.00	0.00	48.75	3.25	3.466667	R
86				1	2	24	2	23	52	3.00	49.00	48.75	3.25	686.9538	S
87	34		2	8	6	10	2	7	69	50.00	19.00	51.75	17.25	0.236715	1 SEG
88	51		1		1				53	53.00	0.00	49.69	3.31	3.533333	R
89	34		6	7	6	10	3	8	74	53.00	21.00	55.50	18.50	0.45045	1 SEG
90	53				1				54	54.00	0.00	50.63	3.38	3.6	R
91	29		3	8	9	10	4	13	76	49.00	27.00	57.00	19.00	4.491228	1 SEG
92	38		6	1	7	14	2	1	69	52.00	17.00	51.75	17.25	0.004831	1 SEG
93	29		5	6	3	9		9	61	43.00	18.00	45.75	15.25	0.661202	1 SEG
94	73		7	2	3	2			87	85.00	2.00	81.56	5.44	2.318008	
95	53		3	6	2				64	64.00	0.00	60.00	4.00	4.266667	R
96	57		2				1		60	59.00	1.00	56.25	3.75	2.151111	R
97						15	6	34	55	0.00	55.00	51.56	3.44	825	S
98									0	0.00	0.00	0.00	0.00	#DIV/0!	
99									0	0.00	0.00	0.00	0.00	#DIV/0!	
100									0	0.00	0.00	0.00	0.00	#DIV/0!	

Appendix C. Disease reaction of F3 families from cross between Chancellor and R107 to Blumeria graminis f. sp. tritici isolate 127.

NO	IT1+2	IT3	IT4	IT5	IT6	IT7	IT8	IT9	TOTAL	OR	OS	ER	ES	X2	NOTE
1	53	10	1		6	12	2	6	90	70.00	20.00	67.50	22.50	0.37037	1 SEG
2						19	5	33	57	0.00	57.00	42.75	14.25	171	SUS
3	53		6	6	11	13	4	7	100	76.00	24.00	75.00	25.00	0.053333	1 SEG
4	59		1	2	6	9	3	5	85	68.00	17.00	63.75	21.25	1.133333	1
5	54								54	54.00	0.00	40.50	13.50	18	R
6					6	16	13	17	52	6.00	46.00	39.00	13.00	111.6923	S
7						6	14	36	56	0.00	56.00	42.00	14.00	168	S
8	51								51	51.00	0.00	38.25	12.75	17	R
9	48		8	8	13	13	3	13	106	77.00	29.00	79.50	26.50	0.314465	1
10					2	19	10	24	55	2.00	53.00	41.25	13.75	149.3879	S
11	51								51	51.00	0.00	38.25	12.75	17	R
12	61		7	1					69	69.00	0.00	51.75	17.25	23	R
13	52								52	52.00	0.00	39.00	13.00	17.33333	R
14	65		6	3	1	7	4	2	88	75.00	13.00	66.00	22.00	4.909091	1
15	50								50	50.00	0.00	37.50	12.50	16.66667	R
16	55								55	55.00	0.00	41.25	13.75	18.33333	R
17	56			1					57	57.00	0.00	42.75	14.25	19	R
18	56		1						57	57.00	0.00	42.75	14.25	19	R
19	48		2		1				51	51.00	0.00	38.25	12.75	17	R
20	44		11	12	7	5	4	9	92	74.00	18.00	69.00	23.00	1.449275	1
21	57		13	2	2	8	6	10	98	74.00	24.00	73.50	24.50	0.013605	1
22						7	3	41	51	0.00	51.00	38.25	12.75	153	S
23	47		14	4	4	7	7	8	91	69.00	22.00	68.25	22.75	0.032967	1
24	43		10	3	6	12	1	9	84	62.00	22.00	63.00	21.00	0.063492	1
25	51								51	51.00	0.00	38.25	12.75	17	R
26						10	1	41	52	0.00	52.00	39.00	13.00	156	S
27	55		3	4		7	3	3	75	62.00	13.00	56.25	18.75	2.351111	1
28	34		6	2	10	14	5	17	88	52.00	36.00	66.00	22.00	11.87879	1
29						8	5	39	52	0.00	52.00	39.00	13.00	156	S
30	52				1				53	53.00	0.00	39.75	13.25	17.66667	R
31	26		5	3	14	15	1	23	87	48.00	39.00	65.25	21.75	18.24138	1
32	47		16	1	4	14		12	94	68.00	26.00	70.50	23.50	0.35461	1
33	34		9	3	12	14	2	5	79	58.00	21.00	59.25	19.75	0.105485	1
34	23		7	3	9	13	6	13	74	42.00	32.00	55.50	18.50	13.13514	1
35	37		13	8	10	6	2	14	90	68.00	22.00	67.50	22.50	0.014815	1
36	52		12	6	7	6	2	11	96	77.00	19.00	72.00	24.00	1.388889	1
37	22		12	11	11	13	1	11	81	56.00	25.00	60.75	20.25	1.485597	1
38						9	4	40	53	0.00	53.00	39.75	13.25	159	S
39	35		10	3	9	4	1	8	70	57.00	13.00	52.50	17.50	1.542857	1
40	38		7	5	10	4	2	6	72	60.00	12.00	54.00	18.00	2.666667	1
41	28		13	5	9	10	8	10	83	55.00	28.00	62.25	20.75	3.37751	1
42	52		2						54	54.00	0.00	40.50	13.50	18	R
43	49		1			1			51	50.00	1.00	38.25	12.75	14.43791	R
44						9	6	38	53	0.00	53.00	39.75	13.25	159	S
45	24		14	2	14	13	1	13	81	54.00	27.00	60.75	20.25	3	1
46	30		6	5	14	17	4	18	94	55.00	39.00	70.50	23.50	13.63121	1
47	28		6	4	12	11		13	74	50.00	24.00	55.50	18.50	2.18018	1
48	50		2	2	1				55	55.00	0.00	41.25	13.75	18.33333	R
49	20		4	4	14	15	1	24	82	42.00	40.00	61.50	20.50	24.73171	1
50	55								55	55.00	0.00	41.25	13.75	18.33333	R
51	53		1						54	54.00	0.00	40.50	13.50	18	R

Appendix C. Continued

NO	IT1+2	IT3	IT4	IT5	IT6	IT7	IT8	IT9	TOTAL	OR	OS	ER	ES	X2	NOTE
52	25		10	7	11	11	1	13	78	53.00	25.00	58.50	19.50	2.068376	1
53	35		6	4	12	11		5	73	57.00	16.00	54.75	18.25	0.369863	1
54						11	7	35	53	0.00	53.00	39.75	13.25	159	S
55						7	12	34	53	0.00	53.00	39.75	13.25	159	S
56	24		13	4	14	16		10	81	55.00	26.00	60.75	20.25	2.176955	1
57	19		8	7	12	20		5	71	46.00	25.00	53.25	17.75	3.948357	1
58					6	28	10	16	60	6.00	54.00	45.00	15.00	135.2	S
59	65				2	14	3	3	87	67.00	20.00	65.25	21.75	0.187739	1
60	55		7	2		4		6	74	64.00	10.00	55.50	18.50	5.207207	1
61	36		11	4	8	5	2	4	70	59.00	11.00	52.50	17.50	3.219048	1
62	54		3						57	57.00	0.00	42.75	14.25	19	R
63						15	8	27	50	0.00	50.00	37.50	12.50	150	S
64	55		9	2	6	9		12	93	72.00	21.00	69.75	23.25	0.290323	1
65	54								54	54.00	0.00	40.50	13.50	18	R
66						14	15	27	56	0.00	56.00	42.00	14.00	168	S
67	45		5	1	4	10	4	5	74	55.00	19.00	55.50	18.50	0.018018	1
68	45		8	5	3	6	1	14	82	61.00	21.00	61.50	20.50	0.01626	1
69	41		12	4	4	11		8	80	61.00	19.00	60.00	20.00	0.066667	1
70	53								53	53.00	0.00	39.75	13.25	17.66667	R
71					1	18	12	27	58	1.00	57.00	43.50	14.50	166.092	S
72	41		10	6	3	7	1	9	77	60.00	17.00	57.75	19.25	0.350649	1
73						7	10	38	55	0.00	55.00	41.25	13.75	165	S
74	32		11	5	12	12	2	4	78	60.00	18.00	58.50	19.50	0.153846	1
75	38		9	5	7	16	2	4	81	59.00	22.00	60.75	20.25	0.201646	1
76	26		4	4	16	21	2	21	94	50.00	44.00	70.50	23.50	23.84397	1
77	37		15	5	5	9	2	3	76	62.00	14.00	57.00	19.00	1.754386	1
78	20		15	5	7	16	2	11	76	47.00	29.00	57.00	19.00	7.017544	1
79	29		8	10	5	9	6	8	75	52.00	23.00	56.25	18.75	1.284444	1
80	38		8	4	1	11	5	4	71	51.00	20.00	53.25	17.75	0.380282	1
81						20	11	22	53	0.00	53.00	39.75	13.25	159	S
82	30		11	4	9	10	2	6	72	54.00	18.00	54.00	18.00	0	1
83						10	12	29	51	0.00	51.00	38.25	12.75	153	S
84	49		3	2					54	54.00	0.00	40.50	13.50	18	R
85					1	14	8	30	53	1.00	52.00	39.75	13.25	151.1006	S
86						6	12	30	48	0.00	48.00	36.00	12.00	144	S
87	53								53	53.00	0.00	39.75	13.25	17.66667	R
88	51								51	51.00	0.00	38.25	12.75	17	R
89	38		12	5		8	3	8	74	55.00	19.00	55.50	18.50	0.018018	1
90	39		7	4	7	9	3	13	82	57.00	25.00	61.50	20.50	1.317073	1
91	2				1	4	6	42	55	3.00	52.00	41.25	13.75	141.8727	S
92	52								52	52.00	0.00	39.00	13.00	17.33333	R
93	17		16	5	5	13	4	10	70	43.00	27.00	52.50	17.50	6.87619	1
94	53								53	53.00	0.00	39.75	13.25	17.66667	R
95						4	1	48	53	0.00	53.00	39.75	13.25	159	S
96	37		10	5	4	11	2	10	79	56.00	23.00	59.25	19.75	0.71308	1
97						12	7	29	48	0.00	48.00	36.00	12.00	144	S
98				1	1	11	10	27	50	2.00	48.00	37.50	12.50	134.4267	S
99	41		7	4	3	7		5	67	55.00	12.00	50.25	16.75	1.79602	1
100	31		12	3	2	6	4	8	66	48.00	18.00	49.50	16.50	0.181818	1

Appendix D. Disease reacion of F3 families from cross between Chancellor and GO4779 to Blumeria graminis f. sp. tritici isolate 127.

NO	IT1+2	IT3	IT4	IT5	IT6	IT7	IT8	IT9	TOTAL	OR	OS	ER	ES	X2	NOTE
1	24		26	6					56	56.00	0.00	42.00	14.00	18.66667	R
2	46		2	3	5	5	1	8	70	56.00	14.00	52.50	17.50	0.933333	1
3	42		6	2	7				57	57.00	0.00	42.75	14.25	19	R
4	43		14	3	2	11	1	9	83	62.00	21.00	62.25	20.75	0.004016	1
5	34		10	1	7	8		13	73	52.00	21.00	54.75	18.25	0.552511	1
6	43		16	1	5	6	1	15	87	65.00	22.00	65.25	21.75	0.003831	1
7	56		9		1	13		6	85	66.00	19.00	63.75	21.25	0.317647	1
8	28		21	6	1				56	56.00	0.00	42.00	14.00	18.66667	R
9	45		16		2	12	4	5	84	63.00	21.00	63.00	21.00	0	1
10	34		15		1				50	50.00	0.00	37.50	12.50	16.66667	R
11	32		39	10	1	12	2	5	101	82.00	19.00	75.75	25.25	2.062706	1
12						14	3	38	55	0.00	55.00	41.25	13.75	165	S
13					7	28	12	9	56	7.00	49.00	42.00	14.00	116.6667	S
14	3		30	12	7				52	52.00	0.00	39.00	13.00	17.33333	R
15							12	41	53	0.00	53.00	39.75	13.25	159	S
16	41		8		1	10	2	2	64	50.00	14.00	48.00	16.00	0.333333	1
17				1	2	12	8	29	52	3.00	49.00	39.00	13.00	132.9231	S
18	3		7	10	12	16	5	12	65	32.00	33.00	48.75	16.25	23.02051	1
19	39		11		2	5	2	7	66	52.00	14.00	49.50	16.50	0.505051	1
20	5		8	1	9	24			47	23.00	24.00	35.25	11.75	17.02837	1
21	38		10		2	2	6	11	69	50.00	19.00	51.75	17.25	0.236715	1
22	26		25	7					58	58.00	0.00	43.50	14.50	19.33333	R
23	40		15		1	7	2	9	74	56.00	18.00	55.50	18.50	0.018018	1
24	25		21	3	2	8	3	10	72	51.00	21.00	54.00	18.00	0.666667	1
25						9	11	35	55	0.00	55.00	41.25	13.75	165	S
26				2	3	12	14	23	54	5.00	49.00	40.50	13.50	124.4691	S
27							19	13	23	0.00	32.00	17.25	5.75	137.087	S
28	25		22	7					54	54.00	0.00	40.50	13.50	18	R
29	46		7		1				54	54.00	0.00	40.50	13.50	18	R
30	44		5	1		8	1	10	69	50.00	19.00	51.75	17.25	0.236715	1
31	15		17	7	2	6	1	23	71	41.00	30.00	53.25	17.75	11.2723	1
32	37		16						53	53.00	0.00	39.75	13.25	17.66667	R
33	44		6	3					53	53.00	0.00	39.75	13.25	17.66667	R
34				3	12	21	9	31	76	15.00	61.00	57.00	19.00	123.7895	S
35						9	12	33	54	0.00	54.00	40.50	13.50	162	S
36					1	15	8	28	52	1.00	51.00	39.00	13.00	148.1026	S
37	43		5			10	3	8	69	48.00	21.00	51.75	17.25	1.086957	1
38	27		27	2					56	56.00	0.00	42.00	14.00	18.66667	R
39						9	14	30	53	0.00	53.00	39.75	13.25	159	S
40					2	12	5	24	43	2.00	41.00	32.25	10.75	113.4961	S
41	19		21	4	1	9	1		55	45.00	10.00	41.25	13.75	1.363636	1
42	3			2	6	15	4	7	37	11.00	26.00	27.75	9.25	40.44144	?
43	51		15		2	10	1	12	91	68.00	23.00	68.25	22.75	0.003663	1
44	17		28	6		4		11	66	51.00	15.00	49.50	16.50	0.181818	1
45	31		11	1		4	2	9	58	43.00	15.00	43.50	14.50	0.022989	1
46					2	7	12	29	50	2.00	48.00	37.50	12.50		S
47				1	5	10	5	32	53	6.00	47.00	39.75	13.25	114.6226	S
48	42		19	3	5	10	2	10	91	69.00	22.00	68.25	22.75	0.032967	1
49	44		7	2	5	7		4	69	58.00	11.00	51.75	17.25	3.019324	1
50	53		1						54	54.00	0.00	40.50	13.50	18	R
51						4	8	38	50	0.00	50.00	37.50	12.50	150	S

Appendix D. Continued

NO	IT1+2	IT3	IT4	IT5	IT6	IT7	IT8	IT9	TOTAL	OR	OS	ER	ES	X2	NOTE
52						4	11	38	53	0.00	53.00	39.75	13.25	159	S
53	31		13	7	3				54	54.00	0.00	40.50	13.50	18	R
54	37		6			12	5	4	64	43.00	21.00	48.00	16.00	2.083333	1
55	43		18	5	7	6	5	10	94	73.00	21.00	70.50	23.50	0.35461	1
56	34		16	1		3	1	15	70	51.00	19.00	52.50	17.50	0.171429	1
57						16	12	25	53	0.00	53.00	39.75	13.25	159	S
58	41		8		1	5	1	9	65	50.00	15.00	48.75	16.25	0.128205	1
59						12	15	27	54	0.00	54.00	40.50	13.50	162	S
60	11		17	18	8	1			55	54.00	1.00	41.25	13.75	15.76364	R
61	29		16	2	2	6	1	9	65	49.00	16.00	48.75	16.25	0.005128	1
62	43		7		1	11		4	66	51.00	15.00	49.50	16.50	0.181818	1
63	54		4	1		9	3	4	75	59.00	16.00	56.25	18.75	0.537778	1
64	40		13		3	7	5	7	75	56.00	19.00	56.25	18.75	0.004444	1
65	23		26	5	1	4	4	10	73	55.00	18.00	54.75	18.25	0.004566	1
66					3	21	12	17	53	3.00	50.00	39.75	13.25	135.9057	S
67						7	13	31	51	0.00	51.00	38.25	12.75	153	S
68						6	12	37	55	0.00	55.00	41.25	13.75	165	S
69	38		10		1	13	2	2	66	49.00	17.00	49.50	16.50	0.020202	1
70	34		14	1	6	7		16	78	55.00	23.00	58.50	19.50	0.837607	1
71	0		5		5	15	5	35	65	10.00	55.00	48.75	16.25	123.2051	S
72	52		7	1	4	9	3	9	85	64.00	21.00	63.75	21.25	0.003922	1
73	31		7	2	1	9	2	6	58	41.00	17.00	43.50	14.50	0.574713	1
74	18		22	11	7				58	58.00	0.00	43.50	14.50	19.33333	R
75	17		22	8	3	8	2	10	70	50.00	20.00	52.50	17.50	0.47619	1
76						23	3	24	50	0.00	50.00	37.50	12.50	150	S
77					13	31	4	7	55	13.00	42.00	41.25	13.75	77.38788	S
78	46		9	2	2	5	2	5	71	59.00	12.00	53.25	17.75	2.483568	1
79	41		14			5	4	8	72	55.00	17.00	54.00	18.00	0.074074	1
80	27		19	8	1				55	55.00	0.00	41.25	13.75	18.33333	R
81	10		37	7					54	54.00	0.00	40.50	13.50	18	R
82	42		14						56	56.00	0.00	42.00	14.00	18.66667	R
83	32		17	2	1	13	1	7	73	52.00	21.00	54.75	18.25	0.552511	1
84	39		16		1	7	3	8	74	56.00	18.00	55.50	18.50	0.018018	1
85	52		7						59	59.00	0.00	44.25	14.75	19.66667	R
86	32		16	3					51	51.00	0.00	38.25	12.75	17	R
87	21		24	6					51	51.00	0.00	38.25	12.75	17	R
88						8	3	40	51	0.00	51.00	38.25	12.75	153	S
89						5	3	43	51	0.00	51.00	38.25	12.75	153	S
90	29		21	3		11	2	10	76	53.00	23.00	57.00	19.00	1.122807	1
91	39		10	1	1	7		13	71	51.00	20.00	53.25	17.75	0.380282	1
92	33		7		1	9		7	57	41.00	16.00	42.75	14.25	0.28655	1
93						1		50	51	0.00	51.00	38.25	12.75	153	S
94			1			2	6	43	52	1.00	51.00	39.00	13.00	148.1026	S
95	5		25	18	3				51	51.00	0.00	38.25	12.75	17	R
96			7	1	5	22	8	20	63	13.00	50.00	47.25	15.75	99.30688	S
97	30		18	2	3	6		13	72	53.00	19.00	54.00	18.00	0.074074	1
98	1		18	28	6				53	53.00	0.00	39.75	13.25	17.66667	R
99	23		20	2	1	4		9	59	46.00	13.00	44.25	14.75	0.276836	1
100									0	0.00	0.00	0.00	0.00	#DIV/0!	

Appendix E. Disease reaction of F3 families from cross between Chancellor and OK75R3645 to Blumeria graminis f. sp. tritici isolate 127.

NO	IT1+2	IT3	IT4	IT5	IT6	IT7	IT8	IT9	TOTAL	OR	OS	ER	ES	X2	NOTE
1	1			1	3	12	1	36	54	5.00	49.00	40.50	13.50	124.4691	S
2					5	18	5	28	56	5.00	51.00	42.00	14.00	130.381	S
3	2		9	5	22	23	0	18	79	38.00	41.00	59.25	19.75	30.48523	S(?)
4	5		12	11	24	22		12	86	52.00	34.00	64.50	21.50	9.689922	1
5	1				4	8	2	46	61	5.00	56.00	45.75	15.25	145.1858	S
6	8		15	11	19	10	1	8	72	53.00	19.00	54.00	18.00	0.074074	1
7	47		6	4	4	2		1	64	61.00	3.00	48.00	16.00	14.08333	R
8	5		14	17	21	16	1	4	78	57.00	21.00	58.50	19.50	0.153846	1
9	11		18	16	20	10	1	8	84	65.00	19.00	63.00	21.00	0.253968	1
10				1	2	8	2	41	54	3.00	51.00	40.50	13.50	138.8889	S
11	3		10	12	21	17	1	9	73	46.00	27.00	54.75	18.25	5.593607	1
12	2		8	11	27	29	3	19	99	48.00	51.00	74.25	24.75	37.12121	1
13	4		10	10	32	21	1	4	82	56.00	26.00	61.50	20.50	1.96748	1
14	20		17	11	2				50	50.00	0.00	37.50	12.50	16.66667	R
15	17		19	9	12	6		1	64	57.00	7.00	48.00	16.00	6.75	1
16						10	6	36	52	0.00	52.00	39.00	13.00	156	S
17	11		14	14	14	14	2	1	70	53.00	17.00	52.50	17.50	0.019048	1
18	30		13	7	5	10	1	5	71	55.00	16.00	53.25	17.75	0.230047	1
19	39		12	2	7	16	2	6	84	60.00	24.00	63.00	21.00	0.571429	1
20	38		11	2	1	11	3	4	70	52.00	18.00	52.50	17.50	0.019048	1
21	40		13	2	1				56	56.00	0.00	42.00	14.00	18.66667	R
22	4		24	12	13	20	2	5	80	53.00	27.00	60.00	20.00	3.266667	1
23	27		16	7	8	10	5	1	74	58.00	16.00	55.50	18.50	0.45045	1
24	11		10	16	11	15	6	14	83	48.00	35.00	62.25	20.75	13.04819	1
25					1	3	7	7	18	1.00	17.00	13.50	4.50	46.2963	S
26	1		1	2	2	21	3	32	62	6.00	56.00	46.50	15.50	141.0968	S
27	24		21	5	7	9	4	7	77	57.00	20.00	57.75	19.25	0.038961	1
28	34		16	7	5				62	62.00	0.00	46.50	15.50	20.66667	R
29	31		19	3	4	10	3	4	74	57.00	17.00	55.50	18.50	0.162162	1
30						8	12	32	52	0.00	52.00	39.00	13.00	156	S
31	27		27	9	6	7			76	69.00	7.00	57.00	19.00	10.10526	R
32					2	12	8	32	54	2.00	52.00	40.50	13.50	146.3951	S
33					1	6	1	36	44	1.00	43.00	33.00	11.00	124.1212	S
34						10	8	32	50	0.00	50.00	37.50	12.50	150	S
35	59		18	2		2	1		82	79.00	3.00	61.50	20.50	19.9187	R
36	23		22	5	9	11	2	1	73	59.00	14.00	54.75	18.25	1.319635	1
37	7		24	13	20	15	1		80	64.00	16.00	60.00	20.00	1.066667	1
38	36		5		3	15	2	16	77	44.00	33.00	57.75	19.25	13.09524	1
39	63		5	1	4	6		3	82	73.00	9.00	61.50	20.50	8.601626	1
40	11		7	7	19	17		12	73	44.00	29.00	54.75	18.25	8.442922	1
41				3	6	26	4	27	66	9.00	57.00	49.50	16.50	132.5455	S
42	5		8	8	21	26	4	7	79	42.00	37.00	59.25	19.75	20.08861	?
43	13		27	7	19	19		19	104	66.00	38.00	78.00	26.00	7.384615	1
44	13		28	16	14	26		8	105	71.00	34.00	78.75	26.25	3.050794	1
45	45		8		1				54	54.00	0.00	40.50	13.50	18	R
46	37		12	19	2				70	70.00	0.00	52.50	17.50	23.33333	R
47	5		25	19	21	15		4	89	70.00	19.00	66.75	22.25	0.632959	1
48						9	9	33	51	0.00	51.00	38.25	12.75	153	S
49	12		17	9	8	16	3	11	76	46.00	30.00	57.00	19.00	8.491228	1
50	24		22	4	10	13	3	17	93	60.00	33.00	69.75	23.25	5.451613	1
51	50		18	12	6				86	86.00	0.00	64.50	21.50	28.66667	R

Appendix E. Continued

NO	IT1+2	IT3	IT4	IT5	IT6	IT7	IT8	IT9	TOTAL	OR	OS	ER	ES	X2	NOTE
52	63				1	1			65	64.00	1.00	48.75	16.25	19.08205	R
53	23		20	6	16	18		16	99	65.00	34.00	74.25	24.75	4.609428	1
54				3	12	31	10	12	68	15.00	53.00	51.00	17.00	101.6471	S
55					3	14	13	30	60	3.00	57.00	45.00	15.00	156.8	S
56	34		18	5	8	11	1	2	79	65.00	14.00	59.25	19.75	2.232068	1
57	52		7	1					60	60.00	0.00	45.00	15.00	20	R
58	49		20	7	5	17	4	2	104	81.00	23.00	78.00	26.00	0.461538	1
59	56		14	5	6	2			83	81.00	2.00	62.25	20.75	22.59036	R
60	52		26	6	5	1			90	89.00	1.00	67.50	22.50	27.39259	R
61	15		22	11	9	16	6	6	85	57.00	28.00	63.75	21.25	2.858824	1
62	32		32	15	8	5	1		93	87.00	6.00	69.75	23.25	17.06452	R
63				2	3	22	12	29	68	5.00	63.00	51.00	17.00	165.9608	S
64	59		10	2	5	9	4	1	90	76.00	14.00	67.50	22.50	4.281481	1
65	49		17	6	8	8	1	2	91	80.00	11.00	68.25	22.75	8.091575	1
66	46		8	1			1		56	55.00	1.00	42.00	14.00	16.09524	R
67	37		11	4	7	6	4	11	80	59.00	21.00	60.00	20.00	0.066667	1
68	50		13	3	5	6	2		79	71.00	8.00	59.25	19.75	9.320675	?
69	1		1	1	3	18	19	19	62	6.00	56.00	46.50	15.50	141.0968	S(?)
70	36		19	3	6	16	2	1	83	64.00	19.00	62.25	20.75	0.196787	1
71	23		19	14	9	20		14	99	65.00	34.00	74.25	24.75	4.609428	1
72	46		10	5		7	18		86	61.00	25.00	64.50	21.50	0.75969	1
73	25		24	7	6	10	2	2	76	62.00	14.00	57.00	19.00	1.754386	1
74	12		11	10	25	18	1	7	84	58.00	26.00	63.00	21.00	1.587302	1
75	1		5	4	23	39		7	79	33.00	46.00	59.25	19.75	46.51899	S(?)
76					3	44	10		57	3.00	54.00	42.75	14.25	147.8421	S
77	40		13						53	53.00	0.00	39.75	13.25	17.66667	R
78						4	8	38	50	0.00	50.00	37.50	12.50	150	S
79	37		12	2	2				53	53.00	0.00	39.75	13.25	17.66667	R
80	39		13	4	11	8	1	2	78	67.00	11.00	58.50	19.50	4.940171	1
81	42		11	6	6	12	2		79	65.00	14.00	59.25	19.75	2.232068	1
82	45		9						54	54.00	0.00	40.50	13.50	18	R
83	35		19	5	1				60	60.00	0.00	45.00	15.00	20	R
84	37		15	6	3	8	1		70	61.00	9.00	52.50	17.50	5.504762	1
85	21		18	6	4	9	1		59	49.00	10.00	44.25	14.75	2.039548	1
86			4	4	12	17	10	10	57	20.00	37.00	42.75	14.25	48.4269	S
87	12		21	11	5	11	2	8	70	49.00	21.00	52.50	17.50	0.933333	1
88			9	7	10	27	2	3	58	26.00	32.00	43.50	14.50	28.16092	S
89			1	2	8	14	9	23	57	11.00	46.00	42.75	14.25	94.32164	S
90	18		17	5	13	14	4	4	75	53.00	22.00	56.25	18.75	0.751111	1
91	52		2			2	30	4	90	54.00	36.00	67.50	22.50	10.8	1
92	13		14	7	12	7	2	3	58	46.00	12.00	43.50	14.50	0.574713	1
93	6		24	12	7	13	2	10	74	49.00	25.00	55.50	18.50	3.045045	1
94						7	9	38	54	0.00	54.00	40.50	13.50	162	S
95	9		22	2	11	15	2	9	70	44.00	26.00	52.50	17.50	5.504762	1
96			1	2	4	21	1	29	58	7.00	51.00	43.50	14.50	122.5057	S(?)
97	4		12	10	20	16	1	5	68	46.00	22.00	51.00	17.00	1.960784	1
98	4		4	4	22	23	4	14	75	34.00	41.00	56.25	18.75	35.20444	?
99	23		15	7	4	5	4	5	63	49.00	14.00	47.25	15.75	0.259259	1
100	18		22	7	2	7	1	8	65	49.00	16.00	48.75	16.25	0.005128	1

Appendix F. Disease reaction of F3 families from cross between Chancellor and Armada to Blumeria graminis f. sp. tritici isolate 127.

NO	IT1+2	IT3	IT4	IT5	IT6	IT7	IT8	IT9	TOTAL	OR	OS	ER	ES	X2	NOTE
1	14		31	28	21				94	94.00	0.00	70.50	23.50	31.3333	R
2	60								60	60.00	0.00	45.00	15.00	20	R
3	70		1		1				72	72.00	0.00	54.00	18.00	24	R
4	51		10	6	5	15	4	7	98	72.00	26.00	73.50	24.50	0.12245	1
5	36		10	9	10	12	2	14	93	65.00	28.00	69.75	23.25	1.29391	1
6	46		12	4	8	14	5		89	70.00	19.00	66.75	22.25	0.63296	1
7	51		6	4	15	17	3	3	99	76.00	23.00	74.25	24.75	0.16498	1
8	45		14	8	7	15	5	10	104	74.00	30.00	78.00	26.00	0.82051	1
9					4	18	13	25	60	4.00	56.00	45.00	15.00	149.422	S
10	51								51	51.00	0.00	38.25	12.75	17	R
11	35		14	11	3	14	4	3	84	63.00	21.00	63.00	21.00	0	1
12	26		16	12	11	21	1	6	93	65.00	28.00	69.75	23.25	1.29391	1
13	22		14	11	21	11	3	21	103	68.00	35.00	77.25	25.75	4.43042	1
14	32		14	12	8	11	3	2	82	66.00	16.00	61.50	20.50	1.31707	1
15	38		12	6	11	13	2	7	89	67.00	22.00	66.75	22.25	0.00375	1
16	52								52	52.00	0.00	39.00	13.00	17.3333	R
17	20		14	11	13	19	5	8	90	58.00	32.00	67.50	22.50	5.34815	1
18					5	39	8	1	53	5.00	48.00	39.75	13.25	121.516	S
19	50		1						51	51.00	0.00	38.25	12.75	17	R
20	27		13	5	5	12	2	11	75	50.00	25.00	56.25	18.75	2.77778	1
21	54		12	6	5	9	3	14	103	77.00	26.00	77.25	25.75	0.00324	1
22	26		9	12	10	14	2	9	82	57.00	25.00	61.50	20.50	1.31707	1
23	40		10	9	4	11	2	4	80	63.00	17.00	60.00	20.00	0.6	1
24	33		12	8	12	10	2	9	86	65.00	21.00	64.50	21.50	0.0155	1
25	50								50	50.00	0.00	37.50	12.50	16.6667	R
26						2	2	46	50	0.00	50.00	37.50	12.50	150	S
27	53				1				54	54.00	0.00	40.50	13.50	18	R
28	55								55	55.00	0.00	41.25	13.75	18.3333	R
29						8	5	37	50	0.00	50.00	37.50	12.50	150	S
30	57								57	57.00	0.00	42.75	14.25	19	R
31	35		9	7	5	9	3	3	71	56.00	15.00	53.25	17.75	0.56808	1
32	57								57	57.00	0.00	42.75	14.25	19	R
33	36		11	16	13	10	4	3	93	76.00	17.00	69.75	23.25	2.24014	1
34	49		8	6	3	13	10	4	93	66.00	27.00	69.75	23.25	0.80645	1
35			1	2	10	27	6	12	58	13.00	45.00	43.50	14.50	85.5402	S
36	39		10	9	3	12	3	7	83	61.00	22.00	62.25	20.75	0.1004	1
37	2		2	4	4	20	17	24	73	12.00	61.00	54.75	18.25	133.521	S(?)
38	55		10		1	7	3	13	89	66.00	23.00	66.75	22.25	0.03371	1
39	49		12	6	4	9	1	2	83	71.00	12.00	62.25	20.75	4.91968	1
40	59		8	4	1	12	8	5	97	72.00	25.00	72.75	24.25	0.03093	1
41	49		6						55	55.00	0.00	41.25	13.75	18.3333	R
42	54								54	54.00	0.00	40.50	13.50	18	R
43						18	19	19	56	0.00	56.00	42.00	14.00	168	S
44	33		16	9	11	6	2	20	97	69.00	28.00	72.75	24.25	0.7732	1
45	30		11	9	6	13	3	8	80	56.00	24.00	60.00	20.00	1.06667	1
46				1	2	18	13	27	61	3.00	58.00	45.75	15.25	159.787	S
47	23		10	3	9	14	5	13	77	45.00	32.00	57.75	19.25	11.2597	1
48	29		15	5	6	22	5	29	111	55.00	56.00	83.25	27.75	38.3453	?
49	32		9	1	18	18	6	13	97	60.00	37.00	72.75	24.25	8.93814	1
50	58								58	58.00	0.00	43.50	14.50	19.3333	R
51	38		11	7	3	8	1	1	69	59.00	10.00	51.75	17.25	4.0628	1

Appendix F. Continued

NO	IT1+2	IT3	IT4	IT5	IT6	IT7	IT8	IT9	TOTAL	OR	OS	ER	ES	X2	NOTE
52	83		8	4	5	3			103	100.00	3.00	77.25	25.75	26.7994	R(?)
53	61								61	61.00	0.00	45.75	15.25	20.3333	R
54	63								63	63.00	0.00	47.25	15.75	21	R
55	61		7	7	7	2			84	82.00	2.00	63.00	21.00	22.9206	R
56	72		8	9	3	2			94	92.00	2.00	70.50	23.50	26.227	R
57	60								60	60.00	0.00	45.00	15.00	20	R
58	4		16	25	20	15	2		82	65.00	17.00	61.50	20.50	0.79675	1
59	75		15	7	11	12	4	1	125	108.00	17.00	93.75	31.25	8.664	1
60				2	5	32	15	5	59	7.00	52.00	44.25	14.75	125.429	S
61	50		16	1	3	13	8	6	97	70.00	27.00	72.75	24.25	0.41581	1
62	45		21	11	1	13	8	3	102	78.00	24.00	76.50	25.50	0.11765	1
63	51		15	6	4	8	3	7	94	76.00	18.00	70.50	23.50	1.71631	1
64	43		13	9	3	8	2	2	80	68.00	12.00	60.00	20.00	4.26667	1
65	37		18	8	4	12	7	9	95	67.00	28.00	71.25	23.75	1.01404	1
66	39		16	4	4	9	8	5	85	63.00	22.00	63.75	21.25	0.03529	1
67	55								55	55.00	0.00	41.25	13.75	18.3333	R
68	54		13	4		1			72	71.00	1.00	54.00	18.00	21.4074	R
69	47		13	8	5	9	4	3	89	73.00	16.00	66.75	22.25	2.34082	1
70	29		11	7	9	15	2	14	87	56.00	31.00	65.25	21.75	5.24521	1
71	35		15	7	8	13		14	92	65.00	27.00	69.00	23.00	0.92754	1
72	36		8	12	19	15		15	105	75.00	30.00	78.75	26.25	0.71429	1
73	32		16	4	7	15	2	16	92	59.00	33.00	69.00	23.00	5.7971	1
74						6	8	40	54	0.00	54.00	40.50	13.50	162	S
75	23		9	6	9	13	9	15	84	47.00	37.00	63.00	21.00	16.254	1
76	22		6	9	13	15	1	18	84	50.00	34.00	63.00	21.00	10.7302	1
77	58		2						60	60.00	0.00	45.00	15.00	20	R
78	38		14	9	3	9	5	11	89	64.00	25.00	66.75	22.25	0.45318	1
79						6	9	39	54	0.00	54.00	40.50	13.50	162	S
80	74		11			4	5	18	112	85.00	27.00	84.00	28.00	0.04762	1
81	38		12	5	6	9	2	9	81	61.00	20.00	60.75	20.25	0.00412	1
82	52								52	52.00	0.00	39.00	13.00	17.3333	R
83						4	9	33	46	0.00	46.00	34.50	11.50	138	S
84	43		9	2	3	8	5	4	74	57.00	17.00	55.50	18.50	0.16216	1
85	52		8	5	3	9	8	6	91	68.00	23.00	68.25	22.75	0.00366	1
86	30		15	7	12	10	7	9	90	64.00	26.00	67.50	22.50	0.72593	1
87	45		7	4	5	12	7	8	88	61.00	27.00	66.00	22.00	1.51515	1
88						8	8	48	64	0.00	64.00	48.00	16.00	192	S
89	47		20	5	5	6	1	15	99	77.00	22.00	74.25	24.75	0.40741	1
90	51		22	2		6	6	14	101	75.00	26.00	75.75	25.25	0.0297	1
91	56								56	56.00	0.00	42.00	14.00	18.6667	R
92	55								55	55.00	0.00	41.25	13.75	18.3333	R
93				1		20	6	28	55	1.00	54.00	41.25	13.75	157.097	S
94	60		8	3	3	6	5	3	88	74.00	14.00	66.00	22.00	3.87879	1
95	31		7	4	9	21	7	25	104	51.00	53.00	78.00	26.00	37.3846	1
96	28		11	5	8	11	5	21	89	52.00	37.00	66.75	22.25	13.0375	1
97	47		18	5	7	5	9	11	102	77.00	25.00	76.50	25.50	0.01307	1
98	50		7						57	57.00	0.00	42.75	14.25	19	R
99	26		8	7	9	11	3	24	88	50.00	38.00	66.00	22.00	15.5152	1
100	53		11	2	7	12	3	7	95	73.00	22.00	71.25	23.75	0.17193	1

Appendix G. Disease reaction of F3 families from cross between Chancellor and SI5 to Blumeria graminis f. sp. tritici isolate 127.

NO	IT1+2	IT3	IT4	IT5	IT6	IT7	IT8	IT9	TOTAL	OR	OS	ER	ES	X2	NOTE
1	47		8	9	6	3		1	74	70.00	4.00	69.38	4.63	0.09009	2
2	31		12	4	5	4	2	2	60	52.00	8.00	56.25	3.75	5.137778	2
3	47		13	8	6	1			75	74.00	1.00	70.31	4.69	3.094222	R
4				11	22	35	2	1	71	33.00	38.00	66.56	4.44	270.769	S(?)
5	27		4	2	3	2			38	36.00	2.00	35.63	2.38	0.063158	2
6	34		17	10	6	12	1	1	81	67.00	14.00	60.75	20.25	2.572016	1
7	23		14	19	13	21			90	69.00	21.00	67.50	22.50	0.133333	1
8	44		15	11	6				76	76.00	0.00	71.25	4.75	5.066667	R
9	3		10	28	10	9	4	2	66	51.00	15.00	49.50	16.50	0.181818	1
10	57		2	1	9	6		1	76	69.00	7.00	71.25	4.75	1.136842	2
11	53								53	53.00	0.00	49.69	3.31	3.533333	R
12	63		8	1	1				73	73.00	0.00	68.44	4.56	4.866667	R
13	55		4	5					64	64.00	0.00	60.00	4.00	4.266667	R
14	4		16	28	20	4			72	68.00	4.00	67.50	4.50	0.059259	2
15	26		17	6	3	13	2	5	72	52.00	20.00	54.00	18.00	0.296296	1
16	53								53	53.00	0.00	49.69	3.31	3.533333	R
17	58								58	58.00	0.00	54.38	3.63	3.866667	R
18	49		7	9	8	5	2	1	81	73.00	8.00	75.94	5.06	1.818107	2
19	49		9	7	1	4	1		71	66.00	5.00	66.56	4.44	0.076056	2
20	34		15	5	9	1			64	63.00	1.00	60.00	4.00	2.4	2
21	74		2	3	4	1			84	83.00	1.00	78.75	5.25	3.669841	R
22	61								61	61.00	0.00	57.19	3.81	4.066667	R
23	63								63	63.00	0.00	59.06	3.94	4.2	R
24	45		10	4	1	8	2	6	76	60.00	16.00	57.00	19.00	0.631579	1
25	59				1				60	60.00	0.00	56.25	3.75	4	R
26	42		7	3	3	3		4	62	55.00	7.00	58.13	3.88	2.688172	2
27	55								55	55.00	0.00	51.56	3.44	3.666667	R
28	54		3						57	57.00	0.00	53.44	3.56	3.8	R
29				33	14	19	1	4	71	47.00	24.00	53.25	17.75	2.934272	1
30	61		1						62	62.00	0.00	58.13	3.88	4.133333	R
31	7		23	25	18	17	1	2	93	73.00	20.00	69.75	23.25	0.605735	1
32	57								57	57.00	0.00	53.44	3.56	3.8	R
33	35		11	5	9	10	2	1	73	60.00	13.00	54.75	18.25	2.013699	1
34	54								54	54.00	0.00	50.63	3.38	3.6	R
35	57								57	57.00	0.00	53.44	3.56	3.8	R
36					1	17	12	31	61	1.00	60.00	57.19	3.81	883.2798	S
37	54		12	4	2	1			73	72.00	1.00	68.44	4.56	2.967123	R
38	44		10	9	1	3			67	64.00	3.00	62.81	4.19	0.359204	2
39	62		5	1					68	68.00	0.00	63.75	4.25	4.533333	R
40				1	4	18	9	26	58	5.00	53.00	54.38	3.63	717.3563	S
41	60		5	4	1	2		1	73	70.00	3.00	68.44	4.56	0.570776	2
42	54		1						55	55.00	0.00	51.56	3.44	3.666667	R
43	11		28	30	7	3			79	76.00	3.00	74.06	4.94	0.81097	2
44	55		5	1					61	61.00	0.00	57.19	3.81	4.066667	R
45	54								54	54.00	0.00	50.63	3.38	3.6	R
46	1		7	31	26	8	5	7	85	65.00	20.00	63.75	21.25	0.098039	1
47	4					20	17	22	63	4.00	59.00	59.06	3.94	821.3344	S(?)
48	48		8	6		4	2		68	62.00	6.00	63.75	4.25	0.768627	2
49	44		1	7	1	3	3		59	53.00	6.00	55.31	3.69	1.546893	2
50			20	42	8	17	4	7	98	70.00	28.00	73.50	24.50	0.666667	1
51	55								55	55.00	0.00	51.56	3.44	3.666667	R

Appendix G. Continued

NO	IT1+2	IT3	IT4	IT5	IT6	IT7	IT8	IT9	TOTAL	OR	OS	ER	ES	X2	NOTE
52			1	8	7	33	11	5	65	16.00	49.00	60.94	4.06	530.2164	S(?)
53	7		23	18	9	2			59	57.00	2.00	55.31	3.69	0.823729	2
54	57		5	1	2	4			69	65.00	4.00	64.69	4.31	0.024155	2
55	65		7	4	1	7	1	1	86	77.00	9.00	80.63	5.38	2.607752	2
56	56								56	56.00	0.00	52.50	3.50	3.733333	R
57	56		5	3	1	1	2		68	65.00	3.00	63.75	4.25	0.392157	2
58	52								52	52.00	0.00	48.75	3.25	3.466667	R
59	64		15	1	4	12	1	3	100	84.00	16.00	75.00	25.00	4.32	1
60	13		25	20	4	1			63	62.00	1.00	59.06	3.94	2.337566	2
61	64		6	6	2	6			84	78.00	6.00	78.75	5.25	0.114286	2
62	22		12	12	12	6	2	1	67	58.00	9.00	62.81	4.19	5.899502	2
63	36		7	3	9	1			56	55.00	1.00	52.50	3.50	1.904762	2
64	81		5	3	2	4	1	1	97	91.00	6.00	90.94	6.06	0.000687	2
65	43		15	16	11	7		2	94	85.00	9.00	88.13	5.88	1.77305	2
66	48		17	12	3	5		3	88	80.00	8.00	82.50	5.50	1.212121	2
67	63		5	1	2				71	71.00	0.00	66.56	4.44	4.733333	R
68	1			4	15	37	2	10	69	20.00	49.00	64.69	4.31	493.9372	S(?)
69	46		5	3		7	1	6	68	54.00	14.00	51.00	17.00	0.705882	1
70	65		7	2	1	6	1	3	85	75.00	10.00	63.75	21.25	7.941176	1
71	44		10	1	6	6	3	4	74	61.00	13.00	55.50	18.50	2.18018	1
72	14		26	17	2	10	2	6	77	59.00	18.00	57.75	19.25	0.108225	1
73	48		18	2					68	68.00	0.00	63.75	4.25	4.533333	R
74	48		7	2	1	9	1	6	74	58.00	16.00	55.50	18.50	0.45045	1
75	12		29	20	8	19	2		90	69.00	21.00	67.50	22.50	0.133333	1
76	45		14	3	1				63	63.00	0.00	59.06	3.94	4.2	R
77	52		7	1	1				61	61.00	0.00	57.19	3.81	4.066667	R
78	54		7	1					62	62.00	0.00	58.13	3.88	4.133333	R
79	52		8	3	2	4	1	7	77	65.00	12.00	57.75	19.25	3.640693	1
80	53								53	53.00	0.00	49.69	3.31	3.533333	R
81	48		8	3					59	59.00	0.00	55.31	3.69	3.933333	R
82	53		4	1					58	58.00	0.00	54.38	3.63	3.866667	R
83	51								51	51.00	0.00	47.81	3.19	3.4	R
84	43		8	5		11	1	6	74	56.00	18.00	55.50	18.50	0.018018	1
85	11		25	21	3	8	1		69	60.00	9.00	51.75	17.25	5.26087	1
86	53								53	53.00	0.00	49.69	3.31	3.533333	R
87	52		12	10	1	6		1	82	75.00	7.00	76.88	5.13	0.731707	2
88	3		16	40	17	1			77	76.00	1.00	72.19	4.81	3.221645	2
89	52		9	12	6	3	1	1	84	79.00	5.00	78.75	5.25	0.012698	2
90	54		14	8	6	3			85	82.00	3.00	79.69	5.31	1.073725	2
91	58		9	6	1	2	1		77	74.00	3.00	72.19	4.81	0.728139	2
92					4	28	12	17	61	4.00	57.00	57.19	3.81	791.4765	S
93	50		7	4		7	2	5	75	61.00	14.00	56.25	18.75	1.604444	1
94	76		6			1	3		86	82.00	4.00	80.63	5.38	0.375194	2
95	47		12	6	2	1	3	1	72	67.00	5.00	67.50	4.50	0.059259	2
96	48		17	6	3				74	74.00	0.00	69.38	4.63	4.933333	R
97	57		10	4	1		3		75	72.00	3.00	70.31	4.69	0.648	2
98	58								58	58.00	0.00	54.38	3.63	3.866667	R
99				1	6	29	12	14	62	7.00	55.00	58.13	3.88	719.4882	S(?)
100	13		25	12	6	5	2		63	56.00	7.00	59.06	3.94	2.540741	2

Appendix H. Disease reaction of F3 families from cross between Chancellor and Bulk PV63-6 to Blumeria graminis f. sp. tritici isolate 127.

NO	IT1+2	IT3	IT4	IT5	IT6	IT7	IT8	IT9	TOTAL	OR	OS	ER	ES	X2	NOTE
1	27		10	7	5	5	1	9	64	49.00	15.00	48.00	16.00	0.083333	1
2			4	3	8	19	4	23	61	15.00	46.00	45.75	15.25	82.67213	S(?)
3					1	6	4	47	58	1.00	57.00	43.50	14.50	166.092	S
4							2	50	52	0.00	52.00	39.00	13.00	156	S
5	11		10	11	19	20	5	14	90	51.00	39.00	67.50	22.50	16.13333	1
6	20		4	9	9	6		9	57	42.00	15.00	42.75	14.25	0.052632	1
7						2	2	43	47	0.00	47.00	35.25	11.75	141	S
8	13		6	14	21	9	3	18	84	54.00	30.00	63.00	21.00	5.142857	1
9	7		7	12	17	17	4	10	74	43.00	31.00	55.50	18.50	11.26126	1
10	52		8	6	5	8	2	2	83	71.00	12.00	62.25	20.75	4.919679	1
11	36		10	10	3	9	1	2	71	59.00	12.00	53.25	17.75	2.483568	1
12	53		3	1					57	57.00	0.00	42.75	14.25	19	R
13	31		10	11	2	6	2	3	65	54.00	11.00	48.75	16.25	2.261538	1
14	49		19	1					69	69.00	0.00	51.75	17.25	23	R
15	20		6	14	7	12		16	75	47.00	28.00	56.25	18.75	6.084444	1
16	26		12	11	6	10		8	73	55.00	18.00	54.75	18.25	0.004566	1
17			1		1	7	12	36	57	2.00	55.00	42.75	14.25	155.3743	S
18	32		16	9	7	7	1	7	79	64.00	15.00	59.25	19.75	1.523207	1
19	31		19	5	8	9	1	4	77	63.00	14.00	57.75	19.25	1.909091	1
20	49		10						59	59.00	0.00	44.25	14.75	19.66667	R
21					1	19	5	32	57	1.00	56.00	42.75	14.25	163.0936	S
22	37		22	10	2				71	71.00	0.00	53.25	17.75	23.66667	R
23	14		15	11	18	15	2	9	84	58.00	26.00	63.00	21.00	1.587302	1
24						10	3	42	55	0.00	55.00	41.25	13.75	165	S
25						5	2	47	54	0.00	54.00	40.50	13.50	162	S
26	17		10	15	12	14		13	81	54.00	27.00	60.75	20.25	3	1
27	16		11	10	12	6		14	69	49.00	20.00	51.75	17.25	0.584541	1
28	51		10	2					63	63.00	0.00	47.25	15.75	21	R
29						7	6	43	56	0.00	56.00	42.00	14.00	168	S
30	24		8	10	7	9		14	72	49.00	23.00	54.00	18.00	1.851852	1
31	32		9	6	7	10		9	73	54.00	19.00	54.75	18.25	0.041096	1
32	24		15	8	3	5	2	8	65	50.00	15.00	48.75	16.25	0.128205	1
33	38		12	3	1	6		11	71	54.00	17.00	53.25	17.75	0.042254	1
34			4	9	19	27	2	20	81	32.00	49.00	60.75	20.25	54.42387	S(?)
35					5	16	15	20	56	5.00	51.00	42.00	14.00	130.381	S
36	24		14	13	13	9	1	12	86	64.00	22.00	64.50	21.50	0.015504	1
37	30		11	9	8	3	2	10	73	58.00	15.00	54.75	18.25	0.771689	1
38	56		2						58	58.00	0.00	43.50	14.50	19.33333	R
39	35		7	6	6	5		2	61	54.00	7.00	45.75	15.25	5.95082	1
40	56		11	1	6	9	1	3	87	74.00	13.00	65.25	21.75	4.693487	1
41	54		5						59	59.00	0.00	44.25	14.75	19.66667	R
42					1	17	9	27	54	1.00	53.00	40.50	13.50	154.0988	S
43	23		12	11	9	8	1	11	75	55.00	20.00	56.25	18.75	0.111111	1
44	45		9						54	54.00	0.00	40.50	13.50	18	R
45			2	7	9	22		17	57	18.00	39.00	42.75	14.25	57.31579	S(?)
46	53		1						54	54.00	0.00	40.50	13.50	18	R
47	30		12	9	7	11		4	73	58.00	15.00	54.75	18.25	0.771689	1
48	17		8	9	9	11		14	68	43.00	25.00	51.00	17.00	5.019608	1
49	26		16	10	12	6	2	9	81	64.00	17.00	60.75	20.25	0.695473	1
50	21		12	10	10	13		6	72	53.00	19.00	54.00	18.00	0.074074	1
51						14	1	40	55	0.00	55.00	41.25	13.75	165	S

Appendix H. Continued

NO	IT1+2	IT3	IT4	IT5	IT6	IT7	IT8	IT9	TOTAL	OR	OS	ER	ES	X2	NOTE
52				3	3	19	3	28	56	6.00	50.00	42.00	14.00	123.4286	S
53	10		5	15	12	12	1	15	70	42.00	28.00	52.50	17.50	8.4	1
54	8		7	7	12	9		8	51	34.00	17.00	38.25	12.75	1.888889	1
55	29		11	6	4	8	1	5	64	50.00	14.00	48.00	16.00	0.333333	1
56	43		1	1					45	45.00	0.00	33.75	11.25	15	R
57				11	26	20	4	2	63	37.00	26.00	47.25	15.75	8.89418	S
58			2	2	12	29	7	16	68	16.00	52.00	51.00	17.00	96.07843	S
59	16		6	8	16	11	3	17	77	46.00	31.00	57.75	19.25	9.562771	1
60	48		11	2					61	61.00	0.00	45.75	15.25	20.33333	R
61						15	11	25	51	0.00	51.00	38.25	12.75	153	S
62	37		13	6	2	6	3	9	76	58.00	18.00	57.00	19.00	0.070175	1
63	54		5	3					62	62.00	0.00	46.50	15.50	20.66667	R
64	50		2		1				53	53.00	0.00	39.75	13.25	17.66667	R
65	26		8	11	7	10		13	75	52.00	23.00	56.25	18.75	1.284444	1
66				1	7	22	5	27	62	8.00	54.00	46.50	15.50	127.5054	S
67				1		10	8	34	53	1.00	52.00	39.75	13.25	151.1006	S
68	22		9	9	13	6	4	3	66	53.00	13.00	49.50	16.50	0.989899	1
69	24		11	11	10	11	2	7	76	56.00	20.00	57.00	19.00	0.070175	1
70	44		15	1					60	60.00	0.00	45.00	15.00	20	R
71	8		5	7	19	10	4	15	68	39.00	29.00	51.00	17.00	11.29412	1
72	33		7	2	4	5	2	8	61	46.00	15.00	45.75	15.25	0.005464	1
73	59					4			63	59.00	4.00	47.25	15.75	11.68783	?
74						14	4	36	54	0.00	54.00	40.50	13.50	162	S
75	52								52	52.00	0.00	39.00	13.00	17.33333	R
76	32		14	11	4	11	1	6	79	61.00	18.00	59.25	19.75	0.206751	1
77	31		8	5	7	8		6	65	51.00	14.00	48.75	16.25	0.415385	1
78	25		16	9	9	13	2	4	78	59.00	19.00	58.50	19.50	0.017094	1
79	31		15	10	8	9	2	2	77	64.00	13.00	57.75	19.25	2.705628	1
80	55		1						56	56.00	0.00	42.00	14.00	18.66667	R
81	2		5	6	25	4	4	6	52	38.00	14.00	39.00	13.00	0.102564	1
82	24		10	8	6	3	2	4	57	48.00	9.00	42.75	14.25	2.578947	1
83	17		1	3	1				22	22.00	0.00	16.50	5.50	7.333333	R
84	31		14	9	2	5		10	71	56.00	15.00	53.25	17.75	0.568075	1
85	25		17	5	3	5		10	65	50.00	15.00	48.75	16.25	0.128205	1
86				1	11	17	6	30	65	12.00	53.00	48.75	16.25	110.8154	S
87	24		12	9	4	9	1	4	63	49.00	14.00	47.25	15.75	0.259259	1
88	54		4	2					60	60.00	0.00	45.00	15.00	20	R
89	21		5	7	7	8		11	59	40.00	19.00	44.25	14.75	1.632768	1
90	6		5	9	14	9		17	60	34.00	26.00	45.00	15.00	10.75556	1
91	12		12	15	15	13	2	19	88	54.00	34.00	66.00	22.00	8.727273	1
92	10		13	14	8	8	1	17	71	45.00	26.00	53.25	17.75	5.112676	1
93	2		2	6	19	19	1	21	70	29.00	41.00	52.50	17.50	42.07619	1
94	17		13	8	9	12		26	85	47.00	38.00	63.75	21.25	17.60392	1
95						18	8	27	53	0.00	53.00	39.75	13.25	159	S
96						1	1	53	55	0.00	55.00	41.25	13.75	165	S
97					4	10	8	31	53	4.00	49.00	39.75	13.25	128.6101	S
98	43		14	2					59	59.00	0.00	44.25	14.75	19.66667	R
99	13		8	9	16	15		20	81	46.00	35.00	60.75	20.25	14.3251	1
100						10	9	35	54	0.00	54.00	40.50	13.50	162	S

Appendix I. Disease reaction of F3 families from cross between Chancellor and VPM1 to Blumeria graminis f. sp. tritici isolate 127.

NO	IT1+2	IT3	IT4	IT5	IT6	IT7	IT8	IT9	TOTAL	OR	OS	ER	ES	X2	NOTE
1	6	3	9	5	9	22	10	3	67	23.00	44.00	16.75	50.25	3.109453	1
2	72		2	8	1				83	82.00	1.00	20.75	62.25	241.0643	R
3	3	7	10	3	8	25	10	8	74	23.00	51.00	18.50	55.50	1.459459	1
4	6	7	8	1	10	13	16	18	79	22.00	57.00	19.75	59.25	0.341772	1
5	14	7	9	1	6	13	10	16	76	31.00	45.00	19.00	57.00	10.10526	1
6								65	65	0.00	65.00	16.25	48.75	21.66667	S
7	16	4	9	3	15	11	17	3	78	32.00	46.00	19.50	58.50	10.68376	1
8	5	6	4	5	24	16	11	8	79	20.00	59.00	19.75	59.25	0.004219	1
9	95		2	6	5				108	103.00	5.00	27.00	81.00	285.2346	R
10	60	1	1	10	13	8	1	1	95	72.00	23.00	23.75	71.25	130.6982	R
11	5	4	12	1	9	7	8	20	66	22.00	44.00	16.50	49.50	2.444444	1
12	62		1	3					66	66.00	0.00	16.50	49.50	198	R
13		3	9	10	12	11	2	2	49	22.00	27.00	12.25	36.75	10.34694	1
14								76	76	0.00	76.00	19.00	57.00	25.33333	S
15	5	9	11	1	13	13	10	18	80	26.00	54.00	20.00	60.00	2.4	1
16	2	9	8	4	9	18	10	1	61	23.00	38.00	15.25	45.75	5.251366	1
17								55	55	0.00	55.00	13.75	41.25	18.33333	S
18								84	84	0.00	84.00	21.00	63.00	28	S
19			3	3	6	7	28	35	82	6.00	76.00	20.50	61.50	13.6748	S
20								68	68	0.00	68.00	17.00	51.00	22.66667	S
21	5	4	12	11	11	10	24	6	83	32.00	51.00	20.75	62.25	8.13253	1
22	2	4	10	2	5	7	7	43	80	18.00	62.00	20.00	60.00	0.266667	1
23								63	63	0.00	63.00	15.75	47.25	21	S
24	5	5	8	4	4	13	28	15	82	22.00	60.00	20.50	61.50	0.146341	1
25	10	7	8	5	7	16	13	7	73	30.00	43.00	18.25	54.75	10.08676	1
26	93								93	93.00	0.00	23.25	69.75	279	R
27	3	13	11	4	7	11	12	6	67	31.00	36.00	16.75	50.25	16.16418	1
28	12	4	6	5	7	9	18	11	72	27.00	45.00	18.00	54.00	6	1
29	11	7	5	1	11	21	16	6	78	24.00	54.00	19.50	58.50	1.384615	1
30					2	1	5	87	95	0.00	95.00	23.75	71.25	31.66667	S
31	7	6	5	1	9	12	16	18	74	19.00	55.00	18.50	55.50	0.018018	1
32								84	84	0.00	84.00	21.00	63.00	28	S
33	102			6	5				113	108.00	5.00	28.25	84.75	300.1799	R
34	4	9	6	7	25	17	6		74	26.00	48.00	18.50	55.50	4.054054	1
35	99		4	6	2		1		112	109.00	3.00	28.00	84.00	312.4286	R
36								88	88	0.00	88.00	22.00	66.00	29.33333	S
37	97			7	3	2			109	104.00	5.00	27.25	81.75	288.2232	R
38	9	6	2		2	12	11	22	64	17.00	47.00	16.00	48.00	0.083333	1
39	9	9	2	1	6	14	16	18	75	21.00	54.00	18.75	56.25	0.36	1
40								89	89	0.00	89.00	22.25	66.75	29.66667	S
41	4	6	7	2	10	9	11	25	74	19.00	55.00	18.50	55.50	0.018018	1
42	6	12	6	2	8	12	20	20	86	26.00	60.00	21.50	64.50	1.255814	1
43	2	5	6	7	14	21	11	2	68	20.00	48.00	17.00	51.00	0.705882	1
44	110								110	110.00	0.00	27.50	82.50	330	R
45	10	8	4	2	7	16	11	19	77	24.00	53.00	19.25	57.75	1.562771	1
46	4	4	3	1	4	11	7	39	73	12.00	61.00	18.25	54.75	2.853881	1
47	8	8	3	1	3	19	14	15	71	20.00	51.00	17.75	53.25	0.380282	1
48	9	6	11	3	4	12	14	28	87	29.00	58.00	21.75	65.25	3.222222	1
49								92	92	0.00	92.00	23.00	69.00	30.66667	S
50		1	8	11	14	16	24	6	80	20.00	60.00	20.00	60.00	0	1
51								85	85	0.00	85.00	21.25	63.75	28.33333	S

Appendix I. Continued

NO	IT1+2	IT3	IT4	IT5	IT6	IT7	IT8	IT9	TOTAL	OR	OS	ER	ES	X2	NOTE
52	103								103	103.00	0.00	25.75	77.25	309	R
53	51		1	3	3	1			59	55.00	4.00	14.75	44.25	146.4463	R
54								112	112	0.00	112.00	28.00	84.00	37.33333	S
55	3	8	12	3	5	25	21	10	87	26.00	61.00	21.75	65.25	1.10728	1
56		13	11	7	19	21	11		82	31.00	51.00	20.50	61.50	7.170732	1
57								91	91	0.00	91.00	22.75	68.25	30.33333	S
58		2	5	4	2			61	74	11.00	63.00	18.50	55.50	4.054054	1
59	68	2	11	10	3	1			95	91.00	4.00	23.75	71.25	253.8982	R
60	11	6	14	7	6	16	10	3	73	38.00	35.00	18.25	54.75	28.49772	1
61	78		6	13	10	3			110	97.00	13.00	27.50	82.50	234.1939	R
62	66		1	10	9	5	2		93	77.00	16.00	23.25	69.75	165.681	R(?)
63	5	6	5	4	2	7	17	41	87	20.00	67.00	21.75	65.25	0.187739	1
64	111								111	111.00	0.00	27.75	83.25	333	R
65	8	7	6	1	3	12	19	20	76	22.00	54.00	19.00	57.00	0.631579	1
66	50		9	6	7	4		4	80	65.00	15.00	20.00	60.00	135	R(?)
67	76		4	4	4	1			89	84.00	5.00	22.25	66.75	228.4981	R
68								65	65	0.00	65.00	16.25	48.75	21.66667	S
69	8	7	7	2		17	19	24	84	24.00	60.00	21.00	63.00	0.571429	1
70	6	9	9	6	11	18	23	18	100	30.00	70.00	25.00	75.00	1.333333	1
71	11	3	5	7	18	14	14	2	74	26.00	48.00	18.50	55.50	4.054054	1
72								83	83	0.00	83.00	20.75	62.25	27.66667	S
73	18	2	11	7	9	11	20	13	91	38.00	53.00	22.75	68.25	13.63004	1
74	13	8	4	1	4	14	23	34	101	26.00	75.00	25.25	75.75	0.029703	1
75	97		4	4					105	105.00	0.00	26.25	78.75	315	R
76				2	10	18	27	13	70	2.00	68.00	17.50	52.50	18.30476	S
77	9	3	1	6	8	17	21	7	72	19.00	53.00	18.00	54.00	0.074074	1
78	11	4		2	5	11	16	27	76	17.00	59.00	19.00	57.00	0.280702	1
79								81	81	0.00	81.00	20.25	60.75	27	S
80	90								90	90.00	0.00	22.50	67.50	270	R
81	82			6	11	1			100	88.00	12.00	25.00	75.00	211.68	R
82	5	4	3	7	21	22	10	4	76	19.00	57.00	19.00	57.00	0	1
83				2	7	9	21	23	62	2.00	60.00	15.50	46.50	15.67742	S
84	74		10	7	2	2			95	91.00	4.00	23.75	71.25	253.8982	R
85	6	3	2	3	11	17	20	14	76	14.00	62.00	19.00	57.00	1.754386	1
86	83		1	3	7	3	1		98	87.00	11.00	24.50	73.50	212.585	R
87								104	104	0.00	104.00	26.00	78.00	34.66667	S
88	12	4	4	1	6	11	21	18	77	21.00	56.00	19.25	57.75	0.212121	1
89								97	97	0.00	97.00	24.25	72.75	32.33333	S
90								87	87	0.00	87.00	21.75	65.25	29	S
91								87	87	0.00	87.00	21.75	65.25	29	S
92	16	8	7	1	17	16	15	4	84	32.00	52.00	21.00	63.00	7.68254	1
93								91	91	0.00	91.00	22.75	68.25	30.33333	S

Appendix J. Disease reaction of F3 families from cross between Chancellor and ST1-25 to Blumeria graminis isolate 127.

NO	IT3	IT4	IT5	IT6	IT7	IT8	IT9	TOTAL	OR	OS	ER	ES	X2	NOTE
1	2	9	12	10	8	9	42	92	23.00	69.00	23.00	69.00	0	1
2	33	27	10	8	1	0	2	81	70.00	11.00	20.25	60.75	162.96708	R(?)
3				3	9	17	32	61	0.00	61.00	15.25	45.75	20.333333	S
4				1	12	7	52	72	0.00	72.00	18.00	54.00	24	S
5	3	14	10	11	11	7	15	71	27.00	44.00	17.75	53.25	6.42723	1
6	1	9	12	8	15	15	10	70	22.00	48.00	17.50	52.50	1.5428571	1
7	8	18	24	10	2	0	0	62	50.00	12.00	15.50	46.50	102.3871	R(?)
8	4	15	27	10	3	1	0	60	46.00	14.00	15.00	45.00	85.422222	R(?)
9	0	8	12	5	9	11	24	69	20.00	49.00	17.25	51.75	0.5845411	1
10	1	2	13	18	13	12	9	68	16.00	52.00	17.00	51.00	0.0784314	1
11	0	13	6	7	9	9	22	66	19.00	47.00	16.50	49.50	0.5050505	1
12	9	20	10	20	8	4	4	75	39.00	36.00	18.75	56.25	29.16	1
13				1	8	8	45	62	0.00	62.00	15.50	46.50	20.666667	S
14				4	8	6	46	64	0.00	64.00	16.00	48.00	21.333333	S
15				1	7	6	42	56	0.00	56.00	14.00	42.00	18.666667	S
16	10	40	16	8	5	3	1	83	66.00	17.00	20.75	62.25	131.57028	R(?)
17		4	8	8	6	9	17	52	12.00	40.00	13.00	39.00	0.1025641	1
18		2	11	13	14	15	9	64	13.00	51.00	16.00	48.00	0.75	1
19		1	3	14	20	17	17	72	4.00	68.00	18.00	54.00	14.518519	S
20	5	14	13	11	14	13	7	77	32.00	45.00	19.25	57.75	11.25974	1
21			2	8	13	11	29	63	2.00	61.00	15.75	47.25	16.005291	S
22			1	4	9	9	35	58	1.00	57.00	14.50	43.50	16.758621	S
23			2	2	9	5	41	59	2.00	57.00	14.75	44.25	14.694915	S
24					2	1	50	53	0.00	53.00	13.25	39.75	17.666667	S
25		1	3	10	17	18	10	59	4.00	55.00	14.75	44.25	10.446328	S
26		5	15	18	13	8	3	62	20.00	42.00	15.50	46.50	1.7419355	1
27		3	14	21	15	8	1	62	17.00	45.00	15.50	46.50	0.1935484	1
28		5	14	17	13	6	16	71	19.00	52.00	17.75	53.25	0.1173709	1
29		3	7	10	8	7	26	61	10.00	51.00	15.25	45.75	2.4098361	1
30					4	1	47	52	0.00	52.00	13.00	39.00	17.333333	S
31			2	3	12	14	38	69	2.00	67.00	17.25	51.75	17.975845	S
32							51	51	0.00	51.00	12.75	38.25	17	S
33			5	5	7	2	61	80	5.00	75.00	20.00	60.00	15	S
34		13	35	10	1			59	48.00	11.00	14.75	44.25	99.937853	R
35		17	13	11	10	4	20	75	30.00	45.00	18.75	56.25	9	1
36							50	50	0.00	50.00	12.50	37.50	16.666667	S
37							50	50	0.00	50.00	12.50	37.50	16.666667	S
38				2	1		50	53	0.00	53.00	13.25	39.75	17.666667	S
39			1	4	5	5	40	55	1.00	54.00	13.75	41.25	15.763636	S
40			1	11	27	6	19	64	1.00	63.00	16.00	48.00	18.75	S
41	14	34	11					59	59.00	0.00	14.75	44.25	177	R
42		12	20	13	4	2	32	83	32.00	51.00	20.75	62.25	8.1325301	1
43							52	52	0.00	52.00	13.00	39.00	17.333333	S
44	2	10	8	5	5	2	27	59	20.00	39.00	14.75	44.25	2.4915254	1
45				1	7	1	60	69	0.00	69.00	17.25	51.75	23	S
46		9	18	12	15	5	8	67	27.00	40.00	16.75	50.25	8.3631841	1
47		23	35	7		1		66	58.00	8.00	16.50	49.50	139.17172	R
48					2		68	70	0.00	70.00	17.50	52.50	23.333333	S
49			3	5	7		56	71	3.00	68.00	17.75	53.25	16.342723	S
50			4	5	2	3	42	56	4.00	52.00	14.00	42.00	9.5238095	S
51							78	78	0.00	78.00	19.50	58.50	26	S

Appendix J. Continued

NO	IT3	IT4	IT5	IT6	IT7	IT8	IT9	TOTAL	OR	OS	ER	ES	X2	NOTE
52		9	14	10	10	10	23	76	23.00	53.00	19.00	57.00	1.122807	1
53		26	30	8	7	2		73	56.00	17.00	18.25	54.75	104.11416	R
54				3	4		82	89	0.00	89.00	22.25	66.75	29.666667	S
55		36	24	8	6	4	7	85	60.00	25.00	21.25	63.75	94.215686	R
56							66	66	0.00	66.00	16.50	49.50	22	S
57		8	13	13	13	11	15	73	21.00	52.00	18.25	54.75	0.5525114	1
58							84	84	0.00	84.00	21.00	63.00	28	S
59		6	17	16	7		28	74	23.00	51.00	18.50	55.50	1.4594595	1
60	1	21	19	13	7		4	65	41.00	24.00	16.25	48.75	50.261538	R
61		9	11	12	11	2	26	71	20.00	51.00	17.75	53.25	0.3802817	1
62		14	12	16	3			45	26.00	19.00	11.25	33.75	25.785185	R
63		2	14	5	4		68	93	16.00	77.00	23.25	69.75	3.0143369	1
64		27	61	10	1	69		99	88.00	11.00	24.75	74.25	215.51852	R
65		11	23	12	7	3	2	58	34.00	24.00	14.50	43.50	34.965517	1
66				1	10	2	57	70	0.00	70.00	17.50	52.50	23.333333	S
67			1	4	4		68	77	1.00	76.00	19.25	57.75	23.069264	S
68				2	7	3	51	63	0.00	63.00	15.75	47.25	21	S
69		3	20	6	6		49	84	23.00	61.00	21.00	63.00	0.2539683	1
70							71	71	0.00	71.00	17.75	53.25	23.666667	S
71			16	7	5		33	61	16.00	45.00	15.25	45.75	0.0491803	1
72			16	8	14	2	28	68	16.00	52.00	17.00	51.00	0.0784314	1
73		2	8	3	8	6	60	87	10.00	77.00	21.75	65.25	8.4636015	1
74	1		9	7	10	7	48	82	10.00	72.00	20.50	61.50	7.1707317	1
75		2	8	9	11	5	34	69	10.00	59.00	17.25	51.75	4.0628019	1
76	1	10	14	15	11	4	18	73	25.00	48.00	18.25	54.75	3.3287671	1
77	2	23	15	9	2	1	11	63	40.00	23.00	15.75	47.25	49.783069	1(?)
78							69	69	0.00	69.00	17.25	51.75	23	S
79	2	17	9	6	7	13	20	74	28.00	46.00	18.50	55.50	6.5045045	1
80		11	21	12	9	9	15	77	32.00	45.00	19.25	57.75	11.25974	1
81		3	14	9	5	13	34	78	17.00	61.00	19.50	58.50	0.4273504	1
82		12	35	11	5	1		64	47.00	17.00	16.00	48.00	80.083333	R
83	2	21	10	10	14	9	9	75	33.00	42.00	18.75	56.25	14.44	1
84							83	83	0.00	83.00	20.75	62.25	27.666667	S
85					2	4	57	63	0.00	63.00	15.75	47.25	21	S
86		1		4	3	1	58	67	1.00	66.00	16.75	50.25	19.746269	S
87		1	4	6	3	1	68	83	5.00	78.00	20.75	62.25	15.939759	S
88		5	14	12	7	7	33	78	19.00	59.00	19.50	58.50	0.017094	1
89		1	3	6	5	11	45	71	4.00	67.00	17.75	53.25	14.201878	S
90		59	20	9	1			89	79.00	10.00	22.25	66.75	192.99251	R
91			1	1	4	4	58	68	1.00	67.00	17.00	51.00	20.078431	S
92		11	18	17	4	3	28	81	29.00	52.00	20.25	60.75	5.0411523	1
93		9	22	14	7	6	29	87	31.00	56.00	21.75	65.25	5.2452107	1
94		10	10	12	14	11	22	79	20.00	59.00	19.75	59.25	0.0042194	1
95				2			77	79	0.00	79.00	19.75	59.25	26.333333	S
96	1	8	11	9	7	7	16	59	20.00	39.00	14.75	44.25	2.4915254	1
97		6	22	9	6	5	44	92	28.00	64.00	23.00	69.00	1.4492754	1
98		1	20	16	6		24	67	21.00	46.00	16.75	50.25	1.4378109	1
99		5	22	14	16	7	3	67	27.00	40.00	16.75	50.25	8.3631841	1
100			1	5	14	14	17	51	1.00	50.00	12.75	38.25	14.437908	S

Appendix K. Disease reaction of F2 progeny, derived from crosses among eight resistant wheat lines, to Blumeria graminis f. sp. tritici isolate 127.

C39/A55-2

NO		CROSS	IT2	IT3	IT4	IT5	IT6	IT7	IT8	IT9	TOTAL	OR	OS	ER	ES	X2(no seg)
1	94-1	C39/A55-2	212		1						213	213.00	0.00	0.00	0.00	#DIV/0!
2	94-2	C39/A55-2	142	0	0	2	0	0	0	0	144	144.00	0.00	0.00	0.00	#DIV/0!
3	94-3	C39/A55-2	248	3	5	0					256	256.00	0.00	0.00	0.00	#DIV/0!
		TOTAL	602	3	6	2	0	0	0	0	613	613.00	0.00	0.00	0.00	#DIV/0!

C39/R107

NO		CROSS	IT2	IT3	IT4	IT5	IT6	IT7	IT8	IT9	TOTAL	OR	OS	ER	ES	X2(no seg)
1	96-1	C39/R107	262	3	4						269	269.00	0.00	0.00	0.00	#DIV/0!
2	96-2	C39/R107	281		1						282	282.00	0.00	0.00	0.00	#DIV/0!
3	96-3	C39/R107	270	4	7	2	2	1	0		286	285.00	1.00	0.00	0.00	#DIV/0!
		TOTAL	813	7	12	2	2	1	0	0	837	836.00	1.00	0.00	0.00	#DIV/0!

GO4779/C39

NO		CROSS	IT2	IT3	IT4	IT5	IT6	IT7	IT8	IT9	TOTAL	OR	OS	ER	ES	X2(4 genes)
1	127-1	Go4779/c39	203				1		1		205	204.00	1.00	204.20	0.80	0.049756
2	127-2	Go4779/c39	199		1			1			201	200.00	1.00	200.21	0.79	0.059019
3	127-3	Go4779/c39	162	1	1			1		1	166	164.00	2.00	165.35	0.65	2.82816
		TOTAL	564	1	2	0	1	2	1	1	572	568.00	4.00	569.77	2.23	1.400686

OK75R3645/C39

NO		CROSS	IT2	IT3	IT4	IT5	IT6	IT7	IT8	IT9	TOTAL	OR	OS	ER	ES	X2(4 genes)
1	121-3	OK75r/c39	251								251	251.00	0.00	250.02	0.98	0.984314
2	121-4	OK75r/c39	200		1			1			202	201.00	1.00	201.21	0.79	0.05661
3	121-5	OK75r/c39	226								226	226.00	0.00	225.12	0.88	0.886275
		TOTAL	677	0	1	0	0	1	0	0	679	678.00	1.00	676.35	2.65	1.033406

Armada/C39

NO		CROSS	IT2	IT3	IT4	IT5	IT6	IT7	IT8	IT9	TOTAL	OR	OS	ER	ES	X2(no seg)
1	"7-1"	"ARMADA/C39	298		2	1					301	301.00	0.00	0.00	0.00	#DIV/0!
2	"7-2"	"ARMADA/C39	253		1	1					255	255.00	0.00	0.00	0.00	#DIV/0!
3	"7-3"	"ARMADA/C39	293		1						294	294.00	0.00	0.00	0.00	#DIV/0!
		TOTAL	844	0	4	2	0	0	0	0	850	850.00	0.00	0.00	0.00	#DIV/0!

C39/SI5

NO		CROSS	IT2	IT3	IT4	IT5	IT6	IT7	IT8	IT9	TOTAL	OR	OS	ER	ES	X2(no seg)
1	97-1	C39/SI-5	249								249	249.00	0.00	0.00	0.00	#DIV/0!
2	97-2	C39/SI-5	273			1					273	274.00	0.00	0.00	0.00	#DIV/0!
3	97-3	C39/SI-5	266	1	1						268	268.00	0.00	0.00	0.00	#DIV/0!
		TOTAL	788	1	1	1	0	0	0	0	790	791.00	0.00	0.00	0.00	#DIV/0!

ST1-25/C39

NO		CROSS	IT2	IT3	IT4	IT5	IT6	IT7	IT8	IT9	TOTAL	OR	OS	253 ER	3 ES	X2(4genes)
1	118-1	ST1/C39	213			3	1	1		2	220	217.00	3.00	217.42	2.58	0.069853
2	118-2	ST1/C39	199			2	3	4	1		209	204.00	5.00	206.55	2.45	2.688056
3	118-3	ST1/C39	146		3		1	1		1	152	150.00	2.00	150.22	1.78	0.027183
		TOTAL	558	0	3	5	5	6	1	3	581	571.00	10.00	574.19	6.81	1.513653

Appendix K. Continued

A55-2/R107

NO		CROSS	IT2	IT3	IT4	IT5	IT6	IT7	IT8	IT9	TOTAL	OR	OS	ER	ES	X2(no seg)
1	101-1	A55-2/R107	243	2	0	0	0	0	0	0	245	245.00	0.00	0.00	0.00	#DIV/0!
2	101-2	A55-2/R107	250	0	0	0	0	0	0	0	250	250.00	0.00	0.00	0.00	#DIV/0!
3	101-3	A55-2/R107	224	2	1	0	0	0	0	0	227	227.00	0.00	0.00	0.00	#DIV/0!
		TOTAL	717	4	1	0	0	0	0	0	722	722.00	0.00	0.00	0.00	#DIV/0!

GO4779/A55-2

NO		CROSS	IT2	IT3	IT4	IT5	IT6	IT7	IT8	IT9	TOTAL	OR	OS	ER	ES	X2(2gene)
1	128-1	GO4779/A55-2	269	0	12	9	6	5	7	10	318	296.00	22.00	298.13	19.88	0.242348
2	128-2	GO4779/A55-2	260	2	7	6	3	6	2	3	289	278.00	11.00	270.94	18.06	2.945559
3	128-3	GO4779/A55-2	258	0	5	6	4	6	2	5	286	273.00	13.00	268.13	17.88	1.418182
		TOTAL	787	2	24	21	13	17	11	18	893	847.00	46.00	837.19	55.81	1.840164

OK75R3645/A55-2

														15	1	
NO		CROSS	IT2	IT3	IT4	IT5	IT6	IT7	IT8	IT9	TOTAL	OR	OS	ER	ES	X2(2genes)
3	122-7	O75R/A55	147		3	2	5	6	2	2	167	157.00	10.00	156.56	10.44	0.019561
		TOTAL	147	0	3	2	5	6	2	2	167	157.00	10.00	156.56	10.44	0.019561

A55-2/Armada

NO		CROSS	IT2	IT3	IT4	IT5	IT6	IT7	IT8	IT9	TOTAL	OR	OS	ER	ES	X2(no seg)
1	24-1	A55-2/ARMADA	282	0	2	1	0	0	0	0	285	285.00	0.00	0.00	0.00	#DIV/0!
2	24-2	A55-2/ARMADA	295	0	1	0	0	0	0	0	296	296.00	0.00	0.00	0.00	#DIV/0!
3	24-3	A55-2/ARMADA	283	1	0	0	0	0	0	0	284	284.00	0.00	0.00	0.00	#DIV/0!
		TOTAL	860	1	3	1	0	0	0	0	865	865.00	0.00	0.00	0.00	#DIV/0!

A55-2/SI5

NO		CROSS	IT2	IT3	IT4	IT5	IT6	IT7	IT8	IT9	TOTAL	OR	OS	ER	ES	X2(no seg)
1	102-1	A55-2/SI-5	253	0	0	0	0	0	0	0	253	253.00	0.00	0.00	0.00	#DIV/0!
2	102-2	A55-2/SI-5	236	0	0	0	0	0	0	0	236	236.00	0.00	0.00	0.00	#DIV/0!
3	102-3	A55-2/SI-5	251	0	0	0	0	0	0	0	251	251.00	0.00	0.00	0.00	#DIV/0!
		TOTAL	740	0	0	0	0	0	0	0	740	740.00	0.00	0.00	0.00	#DIV/0!

ST1-25/A55-2

														13	3	
NO		CROSS	IT2	IT3	IT4	IT5	IT6	IT7	IT8	IT9	TOTAL	OR	OS	ER	ES	X2(2genes)
1	119-6	St1/Arr-2	142		17	17	17	11	14	14	232	193.00	39.00	188.50	43.50	0.572944
2	119-7	St1/Arr-2	127		7	15	8	13	7	5	182	157.00	25.00	147.88	34.13	3.003099
3	119-8	St1/Arr-2	125		5	11	4	6	13	12	176	145.00	31.00	143.00	33.00	0.149184
		TOTAL	394	0	29	43	29	30	34	31	590	495.00	95.00	479.38	110.63	2.71621

R107/GO4779

NO		CROSS	IT2	IT3	IT4	IT5	IT6	IT7	IT8	IT9	TOTAL	OR	OS	ER	ES	X2(2genes)
1		R107/GO4779	91	8	3	0	0	0	2	4	108	102.00	6.00	101.25	6.75	0.088889
2		R107/GO4779	37	2	3	2	3	1	2	4	54	47.00	7.00	50.63	3.38	4.153086
3		R107/GO4779	160	3	2	2	2	3	3	5	180	169.00	11.00	168.75	11.25	0.005926
		TOTAL	288	13	8	4	5	4	7	13	342	318.00	24.00	320.63	21.38	0.34386

Appendix K. Continued

R107/OK75R3645

NO		CROSS	IT2	IT3	IT4	IT5	IT6	IT7	IT8	IT9	TOTAL	OR	OS	ER	ES	X2(Self)
1	109-1	R107/Ok75r3645	273	0	3	1	4	0	0	0	281	281.00	0.00	263.44	17.56	18.73333
2	109-2	R107/Ok75r3645	209	0	1	3	3	3	0	0	219	216.00	3.00	205.31	13.69	8.90137
3	109-3	R107/Ok75r3645	255	0	1	2	3	0	0	0	261	261.00	0.00	244.69	16.31	17.4
		TOTAL	737	0	5	6	10	3	0	0	761	758.00	3.00	713.44	47.56	44.53517

R107/Armada

NO		CROSS	IT2	IT3	IT4	IT5	IT6	IT7	IT8	IT9	TOTAL	OR	OS	ER	ES	X2(no seg)
1	36-1	R107/ARMADA	345	1	2	0	0	0	0	1	349	348.00	1.00	0.00	0.00	#DIV/0!
2	36-2	R107/ARMADA	313	0	0	0	0	0	0	0	313	313.00	0.00	0.00	0.00	#DIV/0!
3	36-3	R107/ARMADA	301	0	0	0	0	0	0	0	301	301.00	0.00	0.00	0.00	#DIV/0!
		TOTAL	959	1	2	0	0	0	0	1	963	962.00	1.00	0.00	0.00	#DIV/0!

R107/SI-5

NO		CROSS	IT2	IT3	IT4	IT5	IT6	IT7	IT8	IT9	TOTAL	OR	OS	ER	ES	X2(no seg)
1	106-1	R107/SI-5	215	0	0	0	0	0	0	0	215	215.00	0.00	0.00	0.00	#DIV/0!
2	106-2	R107/SI-5	252	0	0	0	0	0	0	0	252	252.00	0.00	0.00	0.00	#DIV/0!
3	106-3	R107/SI-5	249	0	0	0	0	0	0	0	249	249.00	0.00	0.00	0.00	#DIV/0!
		TOTAL	716	0	0	0	0	0	0	0	716	716.00	0.00	0.00	0.00	#DIV/0!

R107/St1-25

														13	3	
NO		CROSS	IT2	IT3	IT4	IT5	IT6	IT7	IT8	IT9	TOTAL	OR	OS	ER	ES	X2(2genes)
1	107-1	R107/St1-25	140	1	10	16	23	21	20	2	233	190.00	43.00	189.31	43.69	0.013316
2	107-2	R107/St1-25	124	0	2	10	14	16	13	5	184	150.00	34.00	149.50	34.50	0.008919
3	107-3	R107/St1-25	140	0	9	24	12	16	11	9	221	185.00	36.00	179.56	41.44	0.878176
		TOTAL	404	1	21	50	49	53	44	16	638	525.00	113.00	518.38	119.63	0.451571

OK75R/GO4779

NO		CROSS	IT2	IT3	IT4	IT5	IT6	IT7	IT8	IT9	TOTAL	OR	OS	ER	ES	X2(2genes)
1	126-1	OK75R/GO4779	236	7	17	14	13	11	7	1	306	287.00	19.00	286.88	19.13	0.000871
2	126-2	OK75R/GO4779	235	2	20	19	16	10	7	2	311	292.00	19.00	291.56	19.44	0.010504
3	126-3	OK75R/GO4779	251	4	20	23	16	5	6	3	328	314.00	14.00	307.50	20.50	2.198374
		TOTAL	722	13	57	56	45	26	20	6	945	893.00	52.00	885.94	59.06	0.900811

Go4779/Armada

NO		CROSS	IT2	IT3	IT4	IT5	IT6	IT7	IT8	IT9	TOTAL	OR	OS	ER	ES	X2(2genes)
1	36'-1	Go4779/Armada	56	0	3	1	1	2	1	1	65	61.00	4.00	60.94	4.06	0.001026
2	36'-2	Go4779/Armada	87	1	3	1	2	0	4	2	100	94.00	6.00	93.75	6.25	0.010667
3	36'-3	Go4779/Armada	143	4	4	3	3	6	5	4	172	157.00	15.00	161.25	10.75	1.792248
		TOTAL	286	5	10	5	6	8	10	7	337	312.00	25.00	315.94	21.06	0.785163

SI5/ Go4779

NO		CROSS	IT2	IT3	IT4	IT5	IT6	IT7	IT8	IT9	TOTAL	OR	OS	ER	ES	X2(4 Gs)
1	33'-1	SI5/Go4779	36			1					37	37.00	0.00	36.86	0.14	0.145098
2	33'-2	SI5/Go4779	40								40	40.00	0.00	39.84	0.16	0.156863
3	33'-3	SI5/Go4779	43								43	43.00	0.00	42.83	0.17	0.168627
		TOTAL	119	0	0	1	0	0	0	0	120	120.00	0.00	119.53	0.47	0.470588

Appendix K. Continued

ST1-25/GO4779

NO		CROSS	IT2	IT3	IT4	IT5	IT6	IT7	IT8	IT9	TOTAL	OR	OS	13 ER	3 ES	X2(2genes)
1	120-1	ST1/G4779	238			4	8	21	23	34	328	250.00	78.00	266.50	61.50	5.448405
2	120-2	ST1/G4779	273			5	6	35	21	13	353	284.00	69.00	286.81	66.19	0.147091
3	120-3	ST1/G4779	207			5	7	22	11	19	271	219.00	52.00	220.19	50.81	0.034156
		TOTAL	718	0	0	14	21	78	55	66	952	753.00	199.00	773.50	178.50	2.897651

OK75R/ARMADA

NO		CROSS	IT2	IT3	IT4	IT5	IT6	IT7	IT8	IT9	TOTAL	OR	OS	ER	ES	X2(2genes)
1	83-1	OK75R/ARMADA	214	2	3	12	12	10	3	9	265	243.00	22.00	248.44	16.56	1.904151
2	83-2	OK75R/ARMADA	235	1	5	14	16	13	8	8	300	271.00	29.00	281.25	18.75	5.976889
3	83-3	OK75R/ARMADA	253	0	0	9	15	17	4	2	300	277.00	23.00	281.25	18.75	1.027556
		TOTAL	702	3	8	35	43	40	15	19	865	791.00	74.00	810.94	54.06	7.842852

OK75R/SI5

NO		CROSS	IT2	IT3	IT4	IT5	IT6	IT7	IT8	IT9	TOTAL	OR	OS	ER	ES	X2(4gene)
1	123-1	OK75R/SI5	292	1	3	3	3	0	0	3	305	302.00	3.00	303.81	1.19	2.756271
2	123-2	OK75R/SI5	268	1	7	3	3	2	0	2	286	282.00	4.00	284.88	1.12	7.468038
3	123-3	OK75R/SI5	247	0	6	3	3	4	1	1	265	259.00	6.00	263.96	1.04	23.9059
		TOTAL	807	2	16	9	9	6	1	6	856	843.00	13.00	852.66	3.34	27.99516

SI5/Armada

NO		CROSS	IT2	IT3	IT4	IT5	IT6	IT7	IT8	IT9	TOTAL	OR	OS	ER	ES	X2(no seg)
1	50-1	SI-5/ARMADA	295	0	0	0	0	0	0	0	295	295.00	0.00	0.00	0.00	#DIV/0!
2	50-2	SI-5/ARMADA	220	0	0	0	0	0	0	0	220	220.00	0.00	0.00	0.00	#DIV/0!
3	50-3	SI-5/ARMADA	197	0	0	0	0	0	0	0	197	197.00	0.00	0.00	0.00	#DIV/0!
		TOTAL	712	0	0	0	0	0	0	0	712	712.00	0.00	0.00	0.00	#DIV/0!

Armada/St1-25

NO		CROSS	IT2	IT3	IT4	IT5	IT6	IT7	IT8	IT9	TOTAL	OR	OS	13 ER	3 ES	X2(2 Gs)
1	15'-1	Armada/St1-25	47	0	6	4	0	4	1	5	67	57.00	10.00	54.44	12.56	0.643322
2	15'-2	Armada/St1-25	27	0	6	3	5	2	1	3	47	41.00	6.00	38.19	8.81	1.104746
3	15'-3	Armada/St1-25	27	11	2	7	7	3	0	1	58	54.00	4.00	47.13	10.88	5.349248
4	15'-4	Armada/St1-25	46	0	10	7	8	4	3	4	82	71.00	11.00	66.63	15.38	1.532208
		TOTAL	147	11	24	21	20	13	5	13	254	223.00	31.00	206.38	47.63	7.142742
						6B->Susc.										X2(2 Gs)
		TOTAL	147	11	24	21	13	20	5	13	254	216.00	38.00	206.38	47.63	2.394105

SI5/St1-25

NO		CROSS	IT2	IT3	IT4	IT5	IT6	IT7	IT8	IT9	TOTAL	OR	OS	253/256 ER	3/256 ES	X2(4 Gs)
1	111-1	SI5/St1-25	183	0	3	5	5	2	1	0	199	196.00	3.00	196.67	2.33	0.193596
2	111-2	SI5/St1-25	186	0	2	0	3	0	3	1	195	191.00	4.00	192.71	2.29	1.302125
3	111-3	SI5/St1-25	208	0	4	6	4	3	3	0	228	222.00	6.00	225.33	2.67	4.194716
		TOTAL	577	0	9	11	12	5	7	1	622	609.00	13.00	614.71	7.29	4.527543

Vita

The author, Young-soo Chung, was born July 2, 1961 in Seoul, Korea. He graduated Korea University where he received a Bachelor of Science degree in Agronomy in February, 1984 and a Masters of Science degree in Agronomy in February, 1986. He served in the military from July, 1986 to October, 1988. He was hired by Korea University as a lecturer in September, 1989 and then enrolled in a Ph.D program at V.P.I. & S.U. in the department of Crop and Soil Environmental Sciences in August, 1990. He is married to Misuk Chung and they have a daughter, Hyun-Ju.