Zagazig J. Agric. Res., Vol. 48 No. (1) 2021 103-110

Plant Protection and Pathology Research

Available online at http://zjar.journals.ekb.eg

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INHERITANCE OF ADULT PLANT RESISTANCE TO POWDERY MILDEW IN SOME CROSSES OF BREAD WHEAT

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Received: 10/12/2020 ; Accepted: 10/01/2021

ABSTRACT: Eight F_2 populations of crosses carried out between the resistant cultivar Amigo and 8 susceptible bread wheat cultivars were evaluated to study the inheritance of resistance to powdery mildew (Pm) caused by *Blumeria. graminis* f.sp. *tritici* and also to estimate the number and action of genes related to adult plant resistance. The response to powdery mildew disease was studied in a conditioned glass house and natural infection in the open field. Individual plants were scored and classified as resistant or susceptible according to a specific scale. The tested local wheat cultivars showed susceptible responses at both seedling and adult stages, while the Amigo cultivar was susceptible at seedling stage and resistant at adult stage. The F2 plants of all tested crosses were susceptible at seedling stage and resistant at the adult stage. Obtained results revealed that the inheritance of resistance is ruled by a single gene in the crosses Amigo/Sids12 and Amigo/Misr2; and by two recessive genes in Amigo/Gemmeiza 11 cross. The inheritance of resistance in F2 populations of Amigo/Sakha 95, and Amigo/Giza 171 crosses is controlled by two dominant genes, while in Amigo/Gemmeiza 12, Amigo/Sakha 94 and Amigo/Misr1 crosses is conditioned by two incompatible dominant genes. Sakha 95 and Giza 171 wheat cultivars were the best and suitable for transferring the adult plant resistance gene *Pm*17.

Key words: Powdery mildew, *Blumeria graminis* f.sp. *tritici*, inheritance of resistance, bread wheat.

INTRODUCTION

Powdery mildew (*Blumeria graminis* f. sp. *tritici*) is one of the most important biotic disease affecting wheat production (**Juroszek and Von Tiedemann, 2013**). Host resistance has proved to be the most economical and environmentally safe approach to reduce yield losses. Wild relatives and related species have been widely used as genetic resources for providing new sources of durable resistance to the powdery mildew. Resistance may be related to some species such as *Triticum, Aegilops, Agropyron, Secale, Haynaldia* and *Eremopyron* (**Rubiales *et al*., 1993**). So, the introgression of resistance genes from any of these species may provide new sources of durable resistance to the disease. Common wheat has been genetically improved through the introgression of rye, (*Secale cereale* L. chromatin). The rye chromosome arm 1RS in particular is the most widely incorporated alien variation into the wheat genome since 1930s (**Rabinovich, 1998**). Several resistant genes are located on rye chromosome arms, for example, the powdery mildew resistance genes *Pm*7 and *Pm*8, stripe (yellow) rust resistance gene *Yr*9, stem rust resistance gene *Sr*31 and leaf rust resistance genes *Lr*15 and *Lr*26, all derived from chromosome arm 1RS of Petkus rye while, *Pm*17 came from 1RS of Insave rye (**Singh *et al*., 1990**). Genetic studies confirmed that cultivar 'Amigo', has *Pm17* and leaf rust resistance gene *Lr*24 on a translocated chromosome involving 1 A and 1B, respectively (**Hsam and Zeller, 2006**), the *Pm*8/ *Pm*1 alleles at the locus

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of common wheat (**Mohler *et al*., 2008**) and Amigo is a source of *Sr*24/*Lr*24 (**The *et al*.,1991**). There are many explanations for the number of genes that conditioned resistance to powdery mildew in wheat (**Peusha *et al*., 2002, Srnic, 2003; Ilker *et al*., 2009**). Adult plant resistance (APR) to cereal fungal diseases provide protection in a crop's post-seedling stages typically between tillering and booting according to **Adult Plant Resistance Fact Sheets GRDC, Nov. (2012)**. In Egypt, Amigo cultivar has shown adult-plant resistance (APR) to powdery mildew in the field from 2013 – 2020 seasons (**Elshamy *et al*., 2016; Mohamed and Elkot, 2020**). The aims of this study are to detect gene actions of resistance against powdery mildew and identify the most suitable genotype for transferring the resistance gene *Pm*17 (*Secale cereal*) to 8 susceptible Egyptian bread wheat cultivars.

MATERIALS AND METHODS

Plant Materials

Eight F1 crosses were previously prepared and provided by Dr. Elshamy to clarify the genetic basis of APR to powdery mildew of F2 populations. The Amigo cultivar was crossed as a male parent with eight susceptible bread wheat cultivars in previous study (**Elshamy *et al*., 2019**) at the experimental field of Gemmeiza Agricultural Research Station, ARC, Egypt. Details of the parents are present in Table 1.

Planting Design

Grains of F1 crosses were sown to have F2 plants per each cross in the 2019/2020 growing season. The grains were divided into two groups for evaluation at seedling stage under conditioned glass house and at adult stage under natural field infection

At The Seedling Stage

The grains of each cross as well as the parents were sown as single plants in pots (10 × 10 cm). About 100 to 200 grains for each cross were sown under a conditioned glass house. All the trails were evaluated to powdery mildew as follow:

Fresh fungal conidia of infected samples of wheat powdery mildew collected from commercial wheat fields were initially transferred on the first leaves of the highly susceptible cultivar Chancellor grown in pots (10 × 10 cm diameter) using rubbing technique (**Mago *et al*., 2011**). The inoculated plants placed inside a glass chambers in conditioned glass house. A single colony for each isolate was transferred, using the spatula method on healthy 10-day-old' Chancellor'plants for multiplication. The plants of each trial were inoculated with an aggressive *Bgt* phenotype using rubbing method. Disease severity on each cultivar/cross was rated 8 and 9 days post inoculation using the following scale suggested by **Leath and Heun (1990)** 0 = no symptoms, 1 = faint chlorosis, 2 = chlorotic lesion, 3 = necrotic lesion, 4 = chlorotic lesion with mycelium, 5 = one or two pustules with conidia, 6 = <20% coverage with pustules, 7 = 20 to 50% coverage with pustules, 8 = >50% coverage with medium to large pustules, and 9= approximately 100% coverage with large pustules suggested by. Ratings of 0 to 3 were designated as resistant (R), 4 to 6 as moderat resistance (Mr), and 7 to 9 as susceptible (S).

At The Adult Stage

About 100 to 200 grains of the F2 generation of each cross was drilled into 6 rows, 7m. long in plots on 28th November ,2019/2020season. All plots were surrounded by 1m.border of the susceptible cultivar Chancellor. The F2 plants of each population that could be distinguished readily as separate plants were tagged. Recommended cultural practices were followed, 70 kg N and 100 kg P/fad., fertilizers were applied. Disease assessment was carried out as previously mentioned according to **Leath and Heun (1990)**. Chi-square tests were conducted to test the goodness of fit of the F2 population between observed and expected segregation ratios (**Snedecor and Cochran, 1989**).

$$\chi_c^2 = \frac{\sum (O_i - E_i)^2}{E_i}$$

Where:

C =Degrees of freedom,

O_i =Observed value(s),

E_i =Expected value(s)

Table 1. Genotypes and pedigree of the parental bread wheat cultivar used in this study

Cultivar	Pedigree and selection history
Gemmieza 11	**BOW"S"/KVZ"S"//7C/SERI82/3/GIZA168/SAKHA61**
	CGM7892-2GM-1GM-2GM-0GM
Gemmieza 12	**OTUS/3/SARA/THB//VEE**
	CMSS97YOO227S-5Y-010M-010Y-010M-2Y–1M-0Y-OGM
Sids 12	**BUS//7C//ALD/5/MAYA74/ON//1160.147/3/BB/GLL/4/CHAT"S"/6/MAYA/VUL//CMH74A.630/4*SX.**
	SD7096-4SD-1SD-1SD-0SD
Sakha 94	**OPATA / RAYON // KAUZ**
	CMBW90Y3180-0TOPM-3Y-010M-010M -010Y-10M-015Y-0Y-0AP-0S.
Sakha 95	**PASTOR//SITE/MO/3/CHEN/AEGILOPSSQUARROSA(TAUS)//BCN/4/WBLL1**
	CMSA01Y00158S-040P0Y-040M-030ZTM-040SY-26M-0Y-0SY-0S
Misr 1	**OASIS/KAUZ//4*BCN/3/2*PASTOR**
	CMSS00Y01881T-050M-030Y-030M-030WGY-33M-0Y-0S
Misr 2	**SKAUZ/BAV92**
	CMSS96M03611S-1M-010SY-010M-010S-8M-0Y-0S
Giza 171	**Sakha 93/ Gemmeiza 9**
	Gz 2003-101-1Gz- 4Gz-1Gz-2Gz-0Gz
Amigo	**Teewon"S"/6/Gaucho/4/Tascosa/3/Wichita/Teewon/5/2*Teewon**
	Teewon-Gaucho-63PC42-4-Teewon Sib

RESULTS

Reaction to Powdery Mildew at Seedling and Adult Stages

All the tested local wheat cultivars showed susceptible responses and had a mean disease severity ranged from 7.11 to 7.90 at seedling and from 7 to 9 at the adult stage. Whereas Amigo cultivar showed susceptible response with mean disease severity 7.50 at the seedling stage and completely resistant response at the adult stage (Table 2 and Fig. 1). Also, plants of all F2 populations fell in a category susceptible which mean disease severity ranged from 6.38 (Amigo/Sids12) to 8.00 (Amigo/Sakha95) at seedling stage (Fig. 2). While at adult stage, mean disease severity of all crosses fell in a category resistance ranged from 1.21, 2.36 for crosses Amigo/ Sakha95 and Amigo/ Giza171 to 5.57 Amigo /Gem12 (Fig. 2).

Inheritance of Powdery Mildew Resistance at Adult Stage

The segregation obtained in the F2 generation of the eight crosses to powdery mildew disease is presented in Table 3. The obtained results of Gemmeiza cultivars crosses revealed that, only 56 of the 116 F2 plants from the cross of Amigo/ Gemmeiza11 were scored as resistance, and 60 plants were susceptible, and segregated in a 7R:9S ratio (X^2 = 0. 965, P= 0.326). While, The F2 plants from the cross Amigo/ Gemmeiza 12 showed that 78 out of 84 F2 plants were resistant and 6 of them were susceptible and fit a 15R:1S ratio (X^2 = 0.11, P. 0.73)**.** The obtained results showed that, the F2 plants derived from both of Amigo/Sids12 and Amigo/Misr2 crosses

Table 2. Mean disease severity of the tested wheat cultivars at seedling and adult stages

Wheat cultivar	Seedling stage	Adult stage
Amigo	7.50	0
Gemmeiza 11	7.80	9.00
Gemmeiza 12	7.11	8.00
Sids 12	7.33	9.00
Sakha 94	7.16	8.00
Sakha 95	7.20	7.00
Misr 1	7.85	8.00
Misr 2	7.30	8.00
Giza171	7.90	8.00

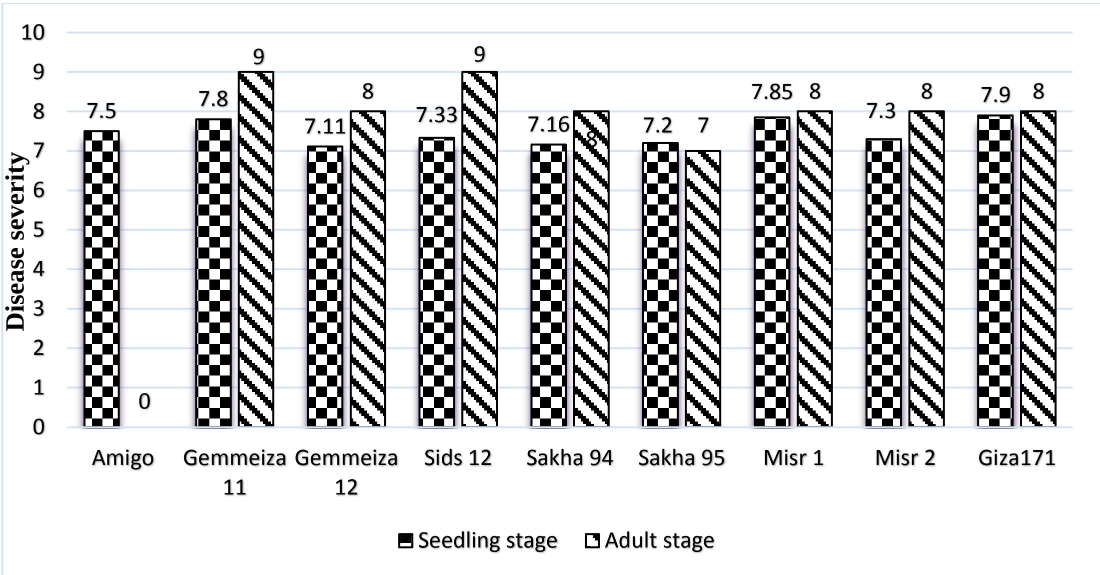

Fig.1. Mean disease severity of tested wheat cultivars at seedling and adult stages

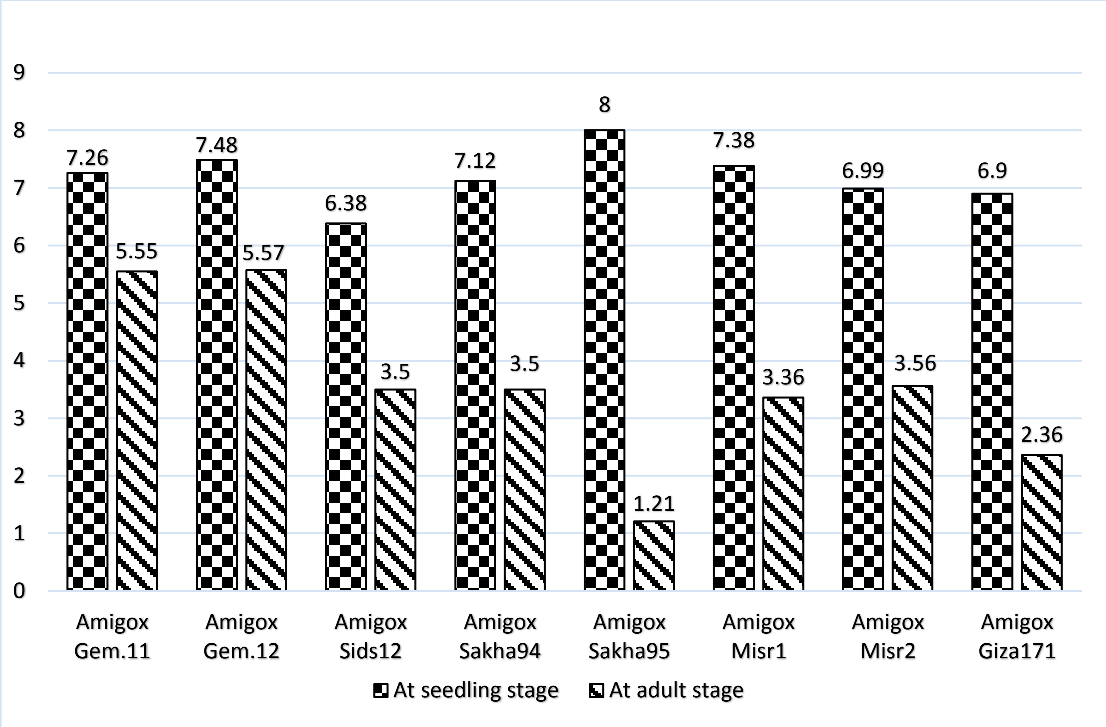

Fig.2. Mean disease severity of eight F2 populations at seedling and adult stages

Table 3. Chi-square values, and heterogeneity of each cross applied to the values obtained at adult stage

Cross	Response			Total plants	Segregation ratio	R	S	$\chi2$	Pat 0.05
	R*	MR	S		R:S				
AmigoxGem11	0	56	60	116	7: 9	56	60	0.965	0.326
AmigoxGem12	18	60	6	84	15:1	78	6	0.11	0.73
AmigoxSids12	54	48	30	132	3:1	102	30	0.346	0.546
AmigoxSakha94	42	60	6	108	15:1	102	6	0.089	0.7656
AmigoxSakha95	90	18	6	114	15:1	108	6	0.191	0.6621
AmigoxMisr1	42	66	6	114	15:1	108	6	0.191	0.6621
AmigoxMisr2	60	42	36	138	3: 1	102	36	0.087	0.7681
AmigoxGiza171	78	36	8	122	15:1	114	8	0.020	0.8885

Degree of freedom =1

* Denotes moderately resistant

segregated in a 3 resistant: 1 susceptible to powdery mildew resistance and fit X^2 value (0.346, 0.087 and P 0.546, 0.7681), respectively. Also, the F2 plants of the crosses Amigo/ Skha94, Amigo/Sakha95, Amigo/Misr1, and Amigo/Giza171 showed segregation of F2 plants fit a 15:1 for resistance to susceptibility and the heterogeneity X^2 values were not significant (00.089. 0.191, 0.191 and 0.020) and probability (0.7656, 0.6621, 0.6621 and 0.8885), respectively. The results showed that the disease severity of the homozygous resistant plants were more than the heterozygous ones in Amigo/ Sakha 95, and Amigo/Giza171 crosses. The reverse was detected in the crosses Amigo/ Gemmeiza12, Amigo/Skha94 and Amigo/ Misr1 crosses wherin the homologous resistance plants were less than the heterozygous ones.

DISCUSSION

Powdery mildew disease is one of the most important diseases that attack wheat crops and cause significant yield losses in Egypt and the world. The objective of the present study was to study the inheritance of F2 plants from crosses between Amigo cultivar and eight local cultivars susceptible to powdery mildew. Amigo had a low level of resistance at seedling stage and a complete resistance response at adult plant resistance. We found the same results in previous studies, (**Elshamy *et al*., 2016; Mohamed and Elkot, 2020**). **Cowger *et al*. (2009)** reported that ratings of powdery mildew severity on the *Pm*17-containing cultivars Amigo and TAM 303 were 4 or 5 on a scale of 0 to 9 In the Kinston and Raleigh regions. The obtained results reveal that F2 plants of all crosses were susceptible to *Blumeria graminis* f. sp. *tritici* at seedling stage and resistant at post-seedling phases which may be described as adult plant resistance. Studies on the inheritance of adult plant resistance to powdery mildew has frequently proved to be complex (**Lillemo *et al*., 2006**). In our study, F2 plants derived from Amigo/Sids12 and Amigo/Misr2 crosses segregated in a 3 resistant: 1 susceptible to powdery mildew resistance indicating the resistance in these crosses conditioned by one dominant gene. **Srnic (2003)** showed that powdery mildew resistance in all Saluda x germplasm line populations segregated as a monogenic trait in the field studies. **Ahmadi *et al*. (2011)** crossed between 'Chinese Spring (CS)' and *T. dicoccoides*, they found that the segregating of BC1F2 fit a 3:1 ratio for resistance to susceptibility supporting the hypothesis of one dominant gene rules the resistance to powdery mildew. Also, F2 plants of Amigo/Gemmeiza11 cross segregated in a 7R: 9S ratio (X^2 = 0.9655, P= 0.3258) indicating that inheritance of resistance is governed by two recessive genes. While, the crosses, Amigo/Gemmeiza12, Amigo/Skha94, Amigo/Sakha95, Amigo/Misr1 and Amigo/ Giza171 showed segregation of F2 plants fit a 15:1 ratio for resistance to susceptibility. The heterogeneity X^2 values of these crosses were not significant. The disease severity of the homozygous resistant plants was more than that of heterozygous ones in Amigo/Sakha95, and Amigo/ Giza171 indicating the presence of two dominant genes governed the inheritance of resistance in these crosses. The reverse was detected in Amigo/Gemmeiza12, Amigo/Skha94 and Amigo/Misr1 crosses indicating that, resistance in these crosses is controlled by two incompatible dominant genes. In accordance with our study, **Ilker *et al.* (2009)** crossed between three wheat cultivars susceptible to powdery mildew (Atilla-12, Basribey and Golia), and five high-yielding genotypes for high levels of partial resistance among 114 powdery mildew resistant genotypes from CIMMYT. A monogenic inheritance was detected in the F2 generation in crosses of parent 48 with two commercial varieties, Atilla-12 and Basribey. While, the inheritance of parent 72 was digenic in crosses with the same commercial varieties. Also, **Peusha *et al.* (2002)** suggested that resistance at the adult stage in wheat cultivars was controlled by two independent dominant genes. In our crosses, there was transgressive segregation indicating that the gene *Pm*17 conferred resistance to all the cultivars at adult stage. Published studies stated that the resistance of soft red winter wheat (*Triticum aestivum* L.) cultivars, McCormick (**Griffey *et al*., 2005a**) and Tribute (**Griffey *et al*., 2005b**) possess *Pm*17 inherited from Amigo. These findings suggest that the isolation of *Pm*8/*Pm*17 from grass species, as well as additional alleles from the rye germplasm, may result in new resistance source used as donors to resistance in wheat breeding programs (**Wulff and Moscou, 2014**).

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وراثة مقاومة النبات البالغ لمرض البياض الدقيقى فى بعض تهجينات قمح الخبز

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تم تقييم ثمانى عشائر من الجيل الثاني لتهجينات بين صنف القمح المقاوم Amigo وثمانية أصناف من قمح الخبز حساسة للإصابة بمرض البياض الدقيقى، وذلك لتقدير عدد الجينات المرتبطة بمقاومة الهجن في طور النبات البالغ للمرض، تمت دراسة الاستجابة لمرض البياض الدقيقي في الصوبة الزجاجية المكيفة و أيضا في الحقل المفتوح تحت ظروف العدوى الطبيعية. تم تسجيل النباتات الفردية وتصنيفها على أنها مقاومة أو حساسة وفقًا لمقياس محدد، أظهرت النتائج أن أصناف القمح المحلية كانت حساسة للإصابة في كل من طورى البادرة والنبات البالغ، بينما كان الصنف الأميجو حساسا للإصابة في طور البادرة ومقاوم في طور النبات البالغ، كانت نباتات الجيل الثاني لجميع الهجن حساسة للاصابة في طور البادرة ومقاومة في طور البلوغ، أظهرت النتائج المتحصل عليها أن وراثة المقاومة يحكمها جين واحد في الهجينين Amigo/Sids12 ، Amigo /Misr2 وجينين متنحيين في الهجين Amigo /Gemmeiza11 ، يتحكم جينين سائدين في وراثة المقاومة لعشائر الجيل الثانى للهجن Amigo/Sakha95 و Amigo / Giza171 بينما يتحكم في وراثة المقاومة جينين سائدين غير متوافقين في الهجن Amigo/Gemmeiza 12، وAmigo/Sakha94 و Amigo/Misr1، كان الصنفين سخا 95 وجيزة 171 هما الأفضل والأنسب لنقل جين المقاومة *Pm*17 فى طور النبات البالغ.

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