Assessing the Suitability of Morphological and Phenotypical Traits to Screen Sesame Accessions for Resistance to Fusarium wilt and Charcoal Rot Diseases

Mohamed Abd El-Hamid Sayied EL-BRAMAWY[1], Salah El-Sayed El-HENDAWY[1] and Waleed Ibrahim SHABAN[2]

[1]Agronomy Department and [2]Agricultural Botany Department, Faculty of Agriculture, Suez Canal University, Ismailia, Egypt

Abstract

El-Bramawy M. A. E.-H. S., El-Hendawy S. E.-S., Shaban W. I. (2009): **Assessing the suitability of morphological and phenotypical traits to screen sesame accessions for resistance to Fusarium wilt and charcoal rot diseases**. Plant Protect. Sci., **45**: 49–58.

Since sesame accessions differ significantly in many morphological and phenotypical traits, some of these traits could be suitable for direct selection for resistance to Fusarium wilt and charcoal rot diseases. Forty-eight sesame accessions that originated from different countries were screened for their reaction to infection by *Fusarium oxysporum* f.sp. *sesami* (FOS) and *Macrophomina phaseolina* (MPH), the Fusarium wilt and charcoal rot pathogens, respectively, in 2005 and 2006. The level of infection and seed yield were measured. Number of branches and days to maturity as morphological traits and seed color as phenotypical trait, which represent some of the diversity among the accessions, were tested for possible correlation with infection percentage. We found that 57, 67 and 67% in 2005, and 77, 77 and 62% in 2006 of the accessions resistant to FOS, and 68, 77 and 64% in 2005, and 80, 76 and 60% in 2006 of the accessions resistant to MPH had a medium branch number, medium maturity and creamy seed colour. According to the analysis of regression, branch number and seed colour were significantly correlated with infection percentages by FOS and/or MPH. Therefore, these traits may be used for direct selection of sesame accessions that are resistant to Fusarium wilt and charcoal rot disease. However, no significant correlations were found between days to maturity and infection percentage by both fungi. Linear regression between infection percentage and three groups of branch number and seed colour indicated that the accessions with medium branch number and creamy or white seed colour were the only covariate which significantly correlated with the infection percentage by FOS and/or MPH.

Keywords: branch number; infection percentage; days to maturity; seed color

Sesame is an important oil crop in tropical and subtropical areas. Its productivity in Egypt, however, remained virtually stagnant over recent decades because of its susceptibility to diseases such as wilt and charcoal rot caused by *Fusarium oxysporum* f.sp. *sesami* (Zaprometoff) Castellani (FOS) and *Macrophomina phaseolina* (Tassi.) Goid. (MPH), respectively. While FOS is a soil borne root pathogen colonising the xylem vessels and blocking them completely to effect wilting (Bateman *et al*. 1996), MPH infects plants at all growth stages, causes poor seedling establishment, and reduces vigor and productivity of older plants (Abawi & Corrales 1989). Most importantly, if no steps are taken to control these pathogens, they may cause heavy yield losses in sesame ranging from

50% to 100% (Gaber *et al*. 1998; Khaleifa 2003; El-Bramawy 2006; El-Shakhess & Khalifa 2007). Although different management methods have been recommended to reduce the effects of the diseases, such as regimes of irrigation, fertilisation and application of systemic fungicides, they are prohibitively expensive, have a negative influence on the environment, and usually are only temporary solutions in the fight against these pathogens (Stevenson 1983; Holley *et al*. 1985). In contrast, a complementary and more permanent approach to minimising the deleterious effects of these pathogens would be to increase the resistance of currently grown genotypes. The use of resistant genotypes is the most desirable control method because it provides a practical, long-term, and environmentally benign means of limiting the damage from these diseases (Wang *et al*. 2001). However, insufficient knowledge of the genetic background of resistance traits, lack of effective selection criteria and evaluation methods have all restricted progress to improve the resistance in current sesame cultivars (El-Bramawy & Abdul Wahid 2006; Kavak & Boydak 2006).

In fact, there is a wide diversity in phenotypical and morphological traits, namely: number of branches and capsules, length of capsules and fruiting zone, time to maturity, and colour of seed have all been demonstrated among sesame accessions (Li *et al*. 1991). The question that arises here is whether any of these criteria are reliable for screening sesame for wilt and charcoal rot pathogens?

Numerous studies have found a relationship between some phenotypical and morphological traits and resistance to diseases. For instance, Dubin *et al*. (1998) and Mahto (2001) found that the resistance of wheat genotypes to Helminthosporium leaf blight was associated with shorter plant height and late maturity. Likewise, several reports have indicated that seed colour can play an important role in resistance of plants to diseases. Statler (1970) reported that common bean plants with a higher total phenols content were more resistant to root-rot disease. Harris and Burns (1973) have also mentioned that tannin involved in seed colour is beneficial in the field due to it providing resistance to fungi. Li *et al*. (1991), Pastor-Corrales *et al*. (1998) and Islam *et al*. (2003) mentioned that polyphenols, of which tannins are a subset, are involved in seed colour expression and are often associated with plant resistance to pathogens or insects. From this point of view, some phenotypical and morphological traits could be valuable tools for screening and breeding of new germplasm for higher diseases resistance. The objective of our study was, therefore, to evaluate the association of some phenotypical and morphological traits of 48 sesame accessions with resistance to wilt and charcoal rot diseases as simple, quick and economic screening criteria.

MATERIALS AND METHODS

Plant materials. Forty-eight accessions of *Sesamum indicum* L. from different countries were used in this study. Ten were obtained from the Agriculture Research Centre, Giza, Egypt; three, i.e. U N. A 130, G N. A 574 and K N. A 592 were obtained from the USA, Greece and north Korea, respectively; 15 promising lines originated from hybridisation and selection in a breeding program at the Experimental Farm of the Faculty of Agriculture, Suez Canal University, Egypt; 20 land races were collected from eight different agro-ecological zones which represented the diversity of distribution of sesame in Egypt. The names, origins, pedigrees and differences in phenotypic and morphological traits of the 48 accessions are listed in Table 1. The tested sesame accessions

Table 1. Names, origin, pedigree and some of the characteristics of 48 sesame accessions used in the experiment

No.	Accession	Origin	Pedigree	Characteristics		
				branching	maturity	seed colour
1	Toshka 1	Egypt	M2 A1 B11 (CAN 114 × Type29) × NA413	medium	mid-late	white
2	Toshka 2	Egypt	M2 A2 B11 (CAN 114 × Type29) × NA413	medium	mid-late	white
3	Toshka 3	Egypt	M2 A3 B11 (CAN 114 × Type29) × NA413	medium	mid-late	creamy
4	Mutants 48	Egypt	Giza 24 D 20 M 3 R-10	medium	mid-late	creamy
5	Mutants 8	Egypt	Giza 24 D 20 M 6 R-12	medium	mid-late	creamy
6	Taka 1	Egypt	not available	medium	mid-late	creamy

Table 1 to be continued

No.	Accession	Origin	Pedigree	Characteristics		
				branching	maturity	seed colour
7	Taka 2	Egypt	not available	medium	mid-late	creamy
8	Taka 3	Egypt	not available	low	early	white
9	Giza 25	Egypt	Giza white × Type9	medium	mid-late	creamy
10	Giza 32	Egypt	B 32 (CAN 114 × Type29)	low	mid-late	white
11	U N. A 130	U.S.A	unknown	medium	early	white
12	G N. A 574	Greece	unknown	medium	mid-late	creamy
13	K N. A 592	Korea	unknown	low	mid-late	creamy
14	H 1	Egypt	Ismailia line 10 × Neu H.B	medium	mid-late	creamy
15	H 2	Egypt	Oro × Local line 274	medium	late	creamy
16	H 3	Egypt	U C. R 10 × Giza 32	low	mid-late	creamy
17	H 4	Egypt	U C. R 11 × Giza 25	high	mid-late	creamy
18	H 5	Egypt	Ismailia line 8 × Ismailia line 20	medium	mid-late	white
19	H 6	Egypt	a cross between two local lines	high	mid-late	black
20	H 7	Egypt	a cross between two local lines	medium	mid-late	creamy
21	H 8	Egypt	a cross between two local lines	medium	mid-late	creamy
22	H 9	Egypt	a cross between two local lines	high	mid-late	creamy
23	H 10	Egypt	a cross between two local lines	medium	mid-late	white
24	S 1	Egypt	selection from local lines under breeding program	medium	mid-late	white
25	S 2	Egypt	selection from local lines under breeding program	medium	mid-late	white
26	S 3	Egypt	selection from local lines under breeding program	high	mid-late	white
27	S 4	Egypt	selection from local lines under breeding program	high	late	white
28	S 5	Egypt	selection from local lines under breeding program	medium	early	white
29	L.R1	Egypt	land race collected from Ismailia Governorate	high	late	creamy
30	L.R2	Egypt	land race collected from El-Sharkia Governorate	medium	mid-late	creamy
31	L.R3	Egypt	land race collected from El-Mina Governorate	medium	late	creamy
32	L.R4	Egypt	land race collected from El-Mina Governorate	high	late	creamy
33	L.R56	Egypt	land race collected from Assuite Governorate	low	early	creamy
34	L.R6	Egypt	land race collected from Assuite Governorate	medium	mid-late	creamy
35	L.R7	Egypt	land race collected from Sohag Governorate	high	mid-late	black
36	L.R8	Egypt	land race collected from Ismailia Governorate	high	late	creamy
37	L.R9	Egypt	land race collected from El-Fayum Governorate	medium	late	white
38	L.R10	Egypt	land race collected from El-Sharkia Governorate	medium	mid-late	white
39	L.R11	Egypt	land race collected from El-Sharkia Governorate	high	early	black
40	L.R12	Egypt	land race collected from Ismailia Governorate	high	late	black
41	L.R13	Egypt	land race collected from El-Fayum Governorate	medium	early	creamy
42	L.R14	Egypt	land race collected from El-Fayum Governorate	low	mid-late	creamy
43	L.R15	Egypt	land race collected from Ismailia Governorate	low	early	creamy
44	L.R16	Egypt	land race collected from Bani Sueif Governorate	low	mid-late	black
45	L.R17	Egypt	land race collected from Bani Sueif Governorate	high	mid-late	creamy
46	L.R18	Egypt	land race collected from Wady El-Gaded Governorate	medium	mid-late	creamy
47	L.R19	Egypt	land race collected from Wady El-Gaded Governorate	medium	late	creamy
48	L.R20	Egypt	land race collected from El-Sharkia Governorate	medium	mid-late	white

were classified by maturity as follows: early is < 110 days to maturity, mid-late 110–125 days, and late > 125 days. The numbers of branches were also categorised: low branching means < 2.12, medium 2.12 to 4.95, and high > 4.95 numbers of branches. The categories of maturity and numbers of branches were done as per 3.5 root loge *n*.

Experimental design and agronomic practices. A randomised complete block design with three replicates was used each season. In 2005 and 2006, the tests were sown in soil known to have a high inocula density of both pathogenic fungi in plots of a long-term sesame research field that was naturally infested with FOS and MPH (El-Bramawy 2006; El-Bramawy & Abdul Wahid 2006).

To confirm infection by FOS and MPH in plants, segments were excised from infected stems and roots, surface sterilised and placed on Petri dishes containing filter paper moistened with sterilised water. The dishes were incubated for 72 h at 25°C. The plant segments were then transferred onto PDA medium in Petri dishes and incubated for 72 h at 25°C. Fungal colonies on the medium were identified as FOS and MPH based on the presence of morphological characters according to Moubasher (1993). Re-isolated cultures of the pathogens were compared with the original isolates to verify a relation between the causal pathogens and the development of diseases.

Each entry was planted in a plot with two soil ridges 60 cm apart and 4 m in length (4.8 m^2). The seeds were planted on the upper third of the ridge in hills with 10 cm between hills. Recommended field practices were carried out at the proper time as usual in the local area. The soil of the experimental area was sandy textured (94.5% and, 2.5% silt and 3.0% clay) with a pH of 7.8.

Assessment of infection percentage. The percentage of plants infected with wilt or charcoal rot were determined by the specific disease symptoms of each fungus, and recorded weekly from 30 days after sowing till the end of the experiment. Plants infected by FOS were characterised by internal vesicular discolouration, appearance of wilt on plants that might die and fall down (considered wilted). Infection by MPH was expressed as root discolouration, black stem rot and a pronounced reduction of the root system (Smith & Carvil 1997).

Scoring accessions for resistance. The levels of infection by FOS and MPH were scored on a 1 to 5 scale on 20 plants that were randomly selected from each plot. The wilted and/or rotted plants were counted and calculated as percentage of infected plants.

A level of infection from 0.1 to 20% was scored 1 and the accession considered resistant (R), infection from 20.1 to 40% was scored 2 and considered moderately resistant (MR), infection from 40.1 to 60% was scored 3 and taken as moderately susceptible (MS), infection from 60.1 to 80% was scored 4 and considered susceptible (S), and infection from 80.1 to 100% was scored 5 and considered to be highly susceptible (HS) (Kavak & Boydak 2006). Data were transformed to arcsine values and prepared for statistical analysis.

Analysis of phenols and tannins. Total phenols were measured using the Folin-Ciocalteu reagent method described by Dev Choudhury and Goswami (1983). Total tannins were determined colourimetrically as described in AOAC (1990). The amount of phenols and tannins are expressed in term of mg/g dry seed.

Statistical analysis. Data were analysed using an analysis of variance of a randomised complete block design, with varieties as the whole plot and replicates as blocks. Statistical analysis was done using CoStat Version 6.311 (CoHort Software, Berkeley). Treatment means were compared using Duncan's multiple test (Steel & Torrie 1980). Probability levels lower than 0.05 or 0.01 were held to be significant. The relations between infection percentages by FOS and MPH and branch number, days to maturity and seed colour were analysed by regressions. The best equations to fit the relations were chosen by regression procedures with selection of forward, backward and stepwise methods. The relationship between the infection percentages by FOS and MPH and three groups of branch number and seed colour were analysed comparing the slopes of the linear regressions using a covariance analysis (Antunez *et al*. 2001). The purpose of this statistical analysis was to determine the variables that significantly contribute to the variation of resistance to the Fusarium wilt and charcoal rot diseases in the sesame accessions.

RESULTS

Highly significant variations were observed among the evaluated accessions in the levels of infection by FOS and MPH and the seed yield (Table 2). Infection by the pathogens varied from 1.7 to 61.6% (FOS) and from 2.2 to 53.4% (MPH) in

Table 2. Percent infection by two soil borne pathogens (*F. oxysporum* and *M. phaseolina*) and seed yield of 48 sesame accessions in 2005 and 2006

No.	Name of accession	*F. oxysporum*						*M. phaseolina*					
		2005			2006			2005			2006		
		infection (%)		yield*	infection (%)		yield*	infection (%)		yield*	infection (%)		yield*
1	Toshka 1	21.7	MR	306.7	16.2	R	323.3	24.2	MR	295.9	16.3	R	343.3
2	Toshka 2	33.2	MR	259.3	20.2	MR	347.9	18.0	R	319.3	3.7	R	380..5
3	Toshka 3	17.1	R	315.0	23.3	MR	290.6	15.3	R	315.7	3.7	R	381.4
4	Mutants 48	25.4	MR	284.3	9.6	R	349.4	20.4	MR	295.4	14.4	R	357.7
5	Mutants 8	16.0	R	326.4	12.9	R	349.2	26.2	MR	293.5	16.5	R	325.8
6	Taka 1	12.1	R	336.5	13.8	R	368.3	15.6	R	325.3	16.1	R	333.8
7	Taka 2	3.4	R	378.8	3.2	R	246.0	9.0	R	352.4	7.9	R	190.0
8	Taka 3	58.9	MS	255.7	47.7	MS	282.8	26.1	MR	332.4	20.1	MR	352.8
9	Giza 25	27.1	MR	271.4	14.2	R	335.2	30.1	MR	198.1	11.6	R	362.7
10	Giza 32	42.7	MS	219.2	19.8	R	310.9	23.5	MR	324.2	20.1	MR	298.6
11	U N. A 130	31.1	MR	264.7	28.0	MR	289.9	14.2	R	269.7	14.2	R	348.2
12	G N. A 574	13.1	R	347.4	6.8	R	374.2	33.4	MR	224.0	25.6	MR	283.3
13	K N. A 592	18.5	R	303.3	9.3	R	226.7	31.9	MR	241.5	13.9	R	286.7
14	H 1	9.2	R	350.5	1.4	R	260.0	10.8	R	339.3	7.1	R	225.0
15	H 2	20.6	MR	330.9	14.9	R	340..9	30.4	MR	277.5	17.6	R	337.6
16	H 3	15.8	R	330.4	14.9	R	335.0	13.2	R	350.1	21.7	MR	298.3
17	H 4	61.6	S	178.14	44.0	MS	222.0	32.5	MR	277.1	21.4	MR	310.7
18	H 5	27.7	MR	297.6	12.8	R	330.8	33.1	MR	267.0	17.9	R	326.8
19	H 6	1.8	R	365.4	2.3	R	376.1	36.8	MR	214.6	23.7	MR	271.9
20	H 7	23.4	MR	292.0	10.8	R	351.5	19.3	R	304.1	9.8	R	350.4
21	H 8	18.8	R	331.3	6.7	R	240.0	19.2	R	309.6	9.8	R	221.7
22	H 9	3.9	R	355.3	7.9	R	346.5	2.2	R	381.6	5.8	R	356.5
23	H 10	41.5	MS	256.0	23.6	MR	160.0	52.2	MS	189.4	42.3	MS	175.0
24	S 1	7.5	R	371.5	9.4	R	378.9	20.0	R	300.5	6.1	R	366.1
25	S 2	1.7	R	373.1	2.7	R	383.2	4.1	R	379.2	3.8	R	364.6
26	S 3	16.7	R	342.8	20.5	MR	303.8	2.6	R	392.1	4.2	R	381.8
27	S 4	20.0	R	306.8	22.7	MR	296.7	16.2	R	329.3	21.8	MR	300.0
28	S 5	6.9	R	369.8	10.1	R	348.4	10.3	R	354.8	10.0	R	355.8
29	L.R1	15.1	R	320.3	21.1	MR	342.3	16.1	R	320.1	22.1	MR	340.1
30	L.R2	25.5	MR	295.1	33.5	MR	315.1	16.1	R	300.1	13.8	R	318.1
31	L.R3	30.3	MR	290.2	32.3	MR	290.2	11.0	R	340.1	17.0	R	378.1
32	L.R4	30.2	MR	290.1	42.2	MS	272.1	20.1	MR	305.2	20.1	MR	293.2
33	L.R56	19.0	R	320.3	21.0	MR	300.3	20.1	MR	330.3	30.1	MR	312.3
34	L.R6	20.2	MR	321.2	26.2	MR	361.2	20.3	MR	340.2	22.3	MR	330.2
35	L.R7	50.2	MS	185.1	54.2	MS	195.1	45.1	MS	240.2	55.1	MS	258.2
36	L.R8	45.6	MS	220.2	38.9	MR	216.4	20.3	MR	285.9	22.3	MR	313.9
37	L.R9	22.9	MR	290.1	16.9	R	308.1	25.1	MR	295.2	31.1	MR	305.2
38	L.R10	38.2	MR	275.2	30.2	MR	265.2	23.3	MR	300.1	19.3	R	356.1

Table 2. to be continued

No.	Name of accession	*F. oxysporum*						*M. phaseolina*					
		2005			2006			2005			2006		
		infection (%)		yield*	infection (%)		yield*	infection (%)		yield*	infection (%)		yield*
39	L.R11	40.7	MS	210.3	48.7	MS	192.3	32.2	MR	320.3	30.2	MR	300.3
40	L.R12	15.8	R	365.1	23.8	MR	351.1	32.1	MR	332.6	26.1	MR	326.6
41	L.R13	16.0	R	321.3	20.0	R	341.3	25.3	MR	295.1	29.3	MR	301.1
42	L.R14	30.1	MR	280.2	24.1	MR	298.2	16.5	R	345.5	20.5	MR	353.5
43	L.R15	15.1	R	350.3	11.1	R	358.3	25.2	MR	305.2	33.2	MR	291.2
44	L.R16	21.2	MR	340.6	17.2	R	342.6	18.1	R	345.1	20.1	MR	355.1
45	L.R17	20.1	MR	300.1	20.1	MR	342.1	19.2	R	320.6	19.2	R	322.6
46	L.R18	25.1	MR	260.5	31.1	MR	276.5	17.0	R	340.9	21.0	MR	358.9
47	L.R19	22.2	MR	300.3	18.2	R	302.3	23.4	MR	345.2	19.4	R	335.2
48	L.R20	45.3	MS	275.1	37.3	MR	287.1	40.2	MS	270.2	48.2	MS	287.2
LSD (0.05)		2.7		25.6	2.6		13.6	2.1		17.7	2.3		12.0

*in kg/FED.; R – resistant; MR – moderately resistant; MS – moderately susceptible; S – susceptible

2005, and from 1.4 to 54.2% (FOS) and from 3.7% to 55.1% (MPH) in 2006. Seed yield ranged from 178.1 to 378.8 kg/Fed (FOS) (Fed = 4200 m^2) and from 181.5 to 392.1 kg/Fed (MPH) in 2005, and from 160.0 to 383.2 kg/Fed (FOS) and from 175.0 to 381.8 kg/Fed (MPH) in 2006 (Table 2).

Most accessions were classified resistant (R) or moderately resistant (MR). Averaged over two seasons, 49.0 and 38% of the accessions were rated R or MR to infection with FOS, and 49.0% and 44% of them to infection with MPH. Only 13% and 7% of the accessions (averaged over two seasons and to infection with FOS and MPH, respectively) were rated to be moderately susceptible (MS).

Interestingly, 57%, 67% and 67% in 2005, and 77%, 77% and 62% in 2006 of the accessions that were rated resistant to FOS, and 68%, 77% and 64% in 2005, and 80%, 76% and 60% in 2006 of the accessions that were rated resistant to MPH had a medium branch number, a medium maturity and creamy seed colour. However, 29%, 19% and 10% in 2005, and 8%, 12% and 8% in 2006 of the accessions considered to be resistant to FOS, and 23%, 9% and 5% in 2005 and 12%, 12% and 0% in 2006 of the accessions resistant to MPH had a high branch number, early maturity and black seed colour.

To determine the predictive and reliable value of branch number, days to maturity and seed colour as screening criteria for resistance to wilt and charcoal rot diseases among sesame accessions, the relationship between these variables and infection percentage were analysed (Table 3). If the coefficient of determination (R^2) is significant, these variables could be useful criteria to evaluate the reaction of sesame accessions to wilt and/or charcoal rot diseases. A quadratic regression equation based on stepwise analysis best fit the relationship. In general, both branch number and seed colour were significantly correlated with the infection percentages by FOS. Seed colour was the only variable which significantly correlated with the infection percentage by MPH. However, days to maturity were not significantly correlated with disease incidence (Table 3).

A linear regression, through a covariance analysis, was used in studying the relationship between the infection percentages by both pathogens, and the branch number and seed colour. In this relationship, the infection percentages were considered as the dependent variables, with the branch number and seed colour as independent variables.

For branch number, all accessions were classified into three groups, low, medium and high branch numbers; and the infection percentage of Fusarium wilt vs. the three groups of branch number were fitted and the equations obtained are:

Table 3. Regression equations and correlation coefficients between infection percentage by *F. oxysporum* f.sp. *sesami* and *M. phaseolina* (Y), and branch number, days to maturity and seed colour (X) in 2005 and 2006

Variables	Infection percentage			
	2005		2006	
	regression equation	R^2	regression equation	R^2
F. oxysporum f.sp. *sesami*				
Branch number	$Y = 37.8 - 9.5\,X + 1.33\,X^2$	0.12^{*}	$Y = 21.0 - 5.0\,X + 1.0\,X^2$	0.27^{**}
Days to maturity	$Y = 526.3 - 8.4\,X + 0.04\,X^2$	0.01^{ns}	$Y = 692.9 - 11.4\,X + 0.05\,X^2$	0.04^{ns}
Seed colour	$Y = 53.8 - 35.5\,X + 9.4\,X^2$	0.20^{**}	$Y = 39.2 - 29.0\,X + 9.0\,X^2$	0.20^{**}
M. phaseolina				
Branch number	$Y = 35.2 - 7.2\,X + 0.9\,X^2$	0.07^{ns}	$Y = 20.8 - 3.1\,X + 0.6\,X^2$	0.06^{ns}
Days to maturity	$Y = 499.5 - 8.1\,X + 0.04\,X^2$	0.02^{ns}	$Y = 296.1 - 4.1\,X + 0.02\,X^2$	0.01^{ns}
Seed colour	$Y = 34.4 - 17.8\,X + 5.5\,X^2$	0.18^{*}	$Y = 22.2 - 10.8\,X + 4.2\,X^2$	0.14^{*}

ns – not significant, $^{*}P = 0.05$, $^{**}P = 0.01$

$$Y = 26.8 - \underset{(t=-1.98)^{0.03}}{7.81\,X_1} - \underset{(t=-0.37)^{0.71}}{2.6\,X_2} \quad (2005) \quad (1)$$

$$Y = 28.9 - \underset{(t=-3.00)^{0.004}}{11.9\,X_1} - \underset{(t=-1.9)^{0.05}}{10.3\,X_2} \quad (2006) \quad (2)$$

where: Y, X_1, X_2 – infection percentage, medium branch and low branch numbers

The infection percentages of charcoal rot vs. the three groups of branch number were fitted and the equations obtained are:

$$Y = 23.0 - \underset{(t=-0.21)^{0.84}}{0.9\,X_1} - \underset{(t=0.52)^{0.61}}{3.0\,X_2} \quad (2005) \quad (3)$$

$$Y = 22.7 - \underset{(t=-1.7)^{0.10}}{6.3\,X_1} - \underset{(t=0.41)^{0.69}}{2.1\,X_2} \quad (2006) \quad (4)$$

where: Y, X_1, X_2 – infection percentage, medium branch and low branch numbers

The results of the above equations indicates that when the relationship between groups of branch number and infection percentage were analysed simultaneously (Eqs (1)–(4)), the accessions with a medium branch number were the only covariate which significantly correlated with the infection percentage by FOS, and had a lower infection by 7.8% and 11.9% than accessions with a high branch number, in 2005 and 2006, respectively (Eqs (1) and (2)).

For seed colour, all accessions were also classified into three groups, creamy, white and black seed colour; and the infection percentages of Fusarium wilt vs. the three groups of seed colour were fitted and the equations obtained are:

$$Y = 31.0 - \underset{(t=-1.93)^{0.05}}{11.3\,X_1} - \underset{(t=0.62)^{0.54}}{3.9\,X_2} \quad (2005) \quad (5)$$

$$Y = 33.2 - \underset{(t=-3.30)^{0.002}}{16.0\,X_1} - \underset{(t=-2.70)^{0.01}}{14.0\,X_2} \quad (2006) \quad (6)$$

where: Y, X_1,X_2 are the infection percentages, creamy seed and white seed colour

The infection percentages of charcoal rot vs. the three groups of seed colour were fitted and the equations obtained are:

$$Y = 31.0 - \underset{(t=-2.01)^{0.05}}{9.9\,X_1} - \underset{(t=-1.66)^{0.10}}{8.8\,X_2} \quad (2005) \quad (7)$$

$$Y = 28.1 - \underset{(t=-2.37)^{0.02}}{10.5\,X_1} - \underset{(t=-2.62)^{0.01}}{12.4\,X_2} \quad (2006) \quad (8)$$

where: Y, X_1,X_2 are the infection percentages, creamy seed and white seed colour

The results of the above equation (Eqs (5)–(8)) indicates that the accessions having creamy and white seed colour were the covariates which significantly correlated with the infection percentage by FOS and MPH; in these accessions infection by FOS was lower by 11.3% and 3.9% in 2005, and by 16.0% and 14.0 in 2006, and infection by MPH was lower by 9.9% and 8.8% in 2005, and by 10.5% and

12.4% in 2006 compared with accessions having black seed colour.

DISCUSSION

Since field studies of plant reaction to a pathogen may be difficult, laborious and time consuming, breeders often search for easily and rapidly evaluated traits that are correlated with resistance. The results of this study indicated that due to the significant relationship between branch number and seed colour, and infection percentage by *Fusarium oxysporum* f.sp. *sesami* (FOS) and/or *Macrophomina phaseolina* (MPH) (Table 3), branch number and seed colour might be suitable traits for direct selection among sesame accessions for resistance to the Fusarium wilt and charcoal rot diseases.

Wu *et al.* (2000) reported that selection for branch number may be significant in developing resistance to root rot disease in *Amaranthus*. Furthermore, Lee and Choi (1986) reported that the germplasm resources of sesame could be classified based on branch number and this trait is controlled by one gene (*nb*) (Brar & Ahuja 1979). This indicates that the trait of branch number may possibly be used as screening criteria if it was associated with the level of infection caused by fungal pathogens. Our results found that branch number was significantly correlated with percent infection caused by FOS, but not with that caused by MPH (Table 3). This result may be due to the fungus of the Fusarium wilt to penetrate plant roots and spread into the stem through the water conducting vessels which causes plants to wilt from the top down or branch by branch, with the plant's vessels plugged and damaged. Our results also found that the accessions with medium or low branch number had a lower infection by FOS by 7.8% and 2.6% in 2005 and 11.9% and 10.3% in 2006 than accessions with high branch numbers (Eqs (1) and (2)). This may be due to favorable conditions for the spread of the pathogen in plants with a high branch number. Furthermore, as infection spreads, the water feeding system becomes blocked, the water uptake is no longer commensurate with transpiration so that the plant becomes more susceptible to fungi and symptom expression increases.

The results of our study found that the levels of infection by Fusarium wilt or charcoal rot were not correlated with days to maturity (Table 3). This suggests that days to maturity are not a suitable trait for direct selection among the sesame accessions for resistance to those diseases. These results may be due to the plants getting infected by either pathogen at any stage of crop development. In this regard, Songa *et al.* (1997) found that time to maturity did not seem to affect the susceptibility or resistance of various bean accessions to MPH.

Our results also found that the sesame accessions having creamy or white seed colour were generally more resistance to Fusarium wilt and charcoal rot diseases than those having black seed colour. These results are confirmed from the linear regression, through a covariance analysis, between the infection percentages caused by FOS and MPH, and the three groups of seed colour (Eqs (5)–(8)). The higher resistance of accessions having creamy and white seed colour to infection with both fungal pathogens may be due to the increased concentrations of total phenols and tannins in their seeds. The average concentrations of these compounds in creamy, white and black seed colour were about 122.0, 77.7 and 74.0 mg per 100 g dry seed for total phenols, and 143.0, 72.7 and 70.0 mg per 100 g dry seed for total tannins, respectively (data not shown). The findings obtained in this study agree well with those reported by Islam *et al.* (2003), who found that polyphenolics, of which tannins are a subset, are involved in seed colour expression and are often associated with plant resistance to pathogens or insects. Statler (1970) also reported that a higher total phenol content in common bean plants gives higher resistance to root-rot disease. Harris and Burns (1973) mentioned that tannin is beneficial in the field due to its presence providing resistance to fungi and seed vivipary. El-Fiki *et al.* (2004) indicated that the amounts of total phenols were obviously higher in sesame entries that were classified as highly resistant and resistant than in those classified as susceptible and highly susceptible. Li *et al.* (1991) found in 2992 accessions of sesame that most accessions resistant to MPH had white seed colours, while black or grey seeded ones tended to be susceptible, and yellow or brown seeded ones intermediate. These and our results may indicate that seed colour could successfully be used to predict the resistance of sesame accessions to fusarium wilt and charcoal rot diseases without conducting tedious field experiments. In addition, we suggest that this desirable phenotypical trait

could be transferred to high-yielding cultivars by using conventional hybridisation, biotechnological and bridge techniques for the introgression of genes for resistance to wilt and charcoal rot diseases.

Acknowledgements. We thank Dr. Khaled M. Yousef and Mr. Ahmed Raian for providing the possibility for chemical analyses.

References

AOAC (1990): Official methods of analysis. Association of Official Analytical Chemists. 15th Ed. Arlington.

Abawi G.S., Corrales P. (1989): Charcoal rot screening procedure and virulence of *Macrophomina phaseolina* isolates on dray edible bean. Turrialba, **39**: 200–207.

Antunez I., Retamosa E.C., Villar R. (2001): Relative growth rate in phylogenetically related deciduous and evergreen woody species. Oecology, **128**: 172–180.

Bateman G.L., Kwasna H., Ward E. (1996): Relationship among *Fusarium* spp. estimated by comparing restriction fragment length polymorphism in polymerase chain reaction amplified nuclear DNA. Canadian Journal of Microbiology, **42**: 1232–1240.

Brar G.S., Ahuja K.L. (1979): Sesame, its culture, genetics breeding and biochemistry. Annual Review of Plant Science, **1**: 245–313.

Dev Choudhury M.N., Goswami M.R. (1983): A raped method for determination of total polyphenolic matters in tea (*Camellia sinensis* L.). Two Bud, **30**: 59–61.

Dubin H.J., Arun B., Begum S.N., Bhatta M., Dhari R., Goel L.B., Joshi A.K., Khanna B.M., Malaker P.K., Pokhrel D.R., Rahman M.M., Saha N.K., Shaheed M.A., Sharma R.C., Singh A.K., Singh R.M., Singh R.V., Vargas M., Verma P.C. (1998): Results of the South Asia regional Helminthosporium leaf blight and yield experiments, 1993–94. In: Duveiller E., Dubin H.J., Reeves J., McNab A. (eds): Helminthosporium Blights of Wheat: Spot Blotch and Tan Spot. CIMMYT, Mexico.

El-Bramawy M.A.S. (2006): Inheritance of resistance to Fusarium wilt in some crosses under field conditions. Plant Protection Science, **42**: 99–105.

El-Bramawy M.A.S., Abdul Wahid O.A. (2006): Field resistance of sesame (*Sesamum indicum* L.) cross-sources to charcoal root rot disease caused by *Macrophomina phaseolina* (Tassi.) Goid. Plant Protection Science, **42**: 66–73.

El-Fiki A.I., El-Deeb F., Mohamed F.G., Khalifa M.M. A. (2004): Controlling sesame charcoal rot incidence by *Macrophomina phaseolina* under field conditions by using the resistant cultivars and some seed and soil treatments. Egyptian Journal of Phytopathology, **32**: 103–118.

El-Shakhess S.A.M., Khalifa M.M.A. (2007): Combining ability and heterosis for yield, yield components, charcoal-rot and Fusarium wilt diseases in sesame. Egyptian Journal of Plant Breeding, **11**: 351–371.

Gaber M.R., Hussein N.A., Saleh O.I. Khalil M.A. (1998): Susceptibility of certain varieties and genotypes and control of wilt and root rot diseases of sesame attributed to *Fusarium oxysporum* f.sp *sesami* and *Macrophomina phaseolina*. Egyptian Journal of Microbiology, **33**: 403–428.

Harris H.B., Burns R.E. (1973): Relationship between tannin content of sorghum grain and preharvest seed molding. Agronomy Journal, **65**: 957–959.

Holley J.D., Hall R., Hofstra G. (1985): Effects of cultivar resistance, leaf wetness duration and temperature on rate of development of potato early blight. Canadian Journal of Plant Science, **65**: 179–184.

Islam F.M.A., Rengifo J., Redden R.J., Basford K.E., Beebe S.E. (2003): Association between seed coat polyphenolics (tannins) and disease resistance in common bean. Plant Foods for Human Nutrition, **58**: 285–297.

Kavak H., Boydak E. (2006): Screening of the resistance levels of 26 sesame breeding lines of Fusarium wilt disease. Plant Pathology Journal, **5**: 157–160.

Khaleifa M.M.A. (2003): Pathological studies on charcoal rot disease of sesame. [PhD. Thesis.] Argonomy Department, Faculty of Agriculture, Zagazig University, Banha Branch, Moshtohor, Qalyoubia, Egypt.

Lee C.H., Choi K.Y. (1986): Genetic studies on quantities characters for sesame breeding. Korean Journal of Breeding, **18**: 242–248. (in Korean)

Li L.L., Wang S.Y., Fang X.P., Hung Z.H., Wang S.T., Li M. L., Cui M.Q. (1991): Identification of *Macrophomina phaseolina* resistant germoplasm of sesame in China. Oil Crops of China, **1**: 23.

Mahto B.N. (2001): Effect of Helminthosporium leaf blight on yield components and determination of resistance in selected wheat varieties. Annual Agriculture Research, **22**: 177–181.

Moubasher A.H. (1993): Soil fungi in Qatar and other Arab countries. The Scientific and Applied Research Centre, University of Qatar.

Pastor-Corrales M.A., Jara C., Singh S.P. (1998): Pathogenic variation in sources of and breeding for resistance to *Phaeoisariopsis griseola* causing angular leaf spot in common bean. Euphytica, **103**: 161–171.

Smith G.S., Carvil O.N. (1997): Field screening of commercial and experimental soybean cultivars for

their reaction to *Macrophomina phaseolina*. Plant Disease, **81**: 363–368.

Songa W., Hillocks R.J., Mwangombe A.W., Buruchara R., Ronno W.K. (1997): Screening common bean accessions for resistance to charcoal rot (*Macrophomina phaseolina*) in eastern Kenya. Experimental Agriculture, **33**: 459–468.

Statler G.D. (1970): Resistance of bean plants to *Fusarium solani* f.sp. *phaseoli*. Plant Disease Report, **54**: 698–699.

Steel R. G.D., Torrie J.H. (1980): Principles and Procedures of Statistics. 2nd Ed. McGraw-Hill, New York.

Stevenson W.R. (1983): Evaluation of fungicides for control of potato early blight. In: Fungicide and Nematicide Test Results of 1982. American Phytopathological Society, St. Paul: 38.

Wang M., Farnham M.W., Thomas C.E. (2001): Inheritance of true leaf stage downy mildew resistance in broccoli. Journal of American Society of Horticulture Science, **126**: 727–729.

Wu H., Sun M., Yue S., Sun H., Cai Y., Huang R., Brenner D., Corke H. (2000): Field evaluation of an *Amaranthus* genetic resource collection in China. Genetic Resources and Crop Evolution, **47**: 43–53.

Received for publication April 22, 2008
Accepted after corrections April 8, 2009

Corresponding author:

Assoc. Prof. Dr. Mohamed A. S. El-Bramawy, Suez Canal University, Faculty of Agriculture, Agronomy Department, 41522 Ismailia, Egypt
tel.: + 20 643 363 363, + 20 127 223 052, fax: + 20 643 201 793, e-mail: el_bramawy71@hotmail.com