SVU-International Journal of Agricultural Sciences
Volume 4 Issue (2) pp.: 84-95, 2022
Print ISSN 2636-3801 | Online ISSN 2636-381X
Doi: 10.21608/svuijas.2022.126619.1195

RESEARCH ARTICLE

Disease severity and correlation study for eight sesame cultivars undergoing Fusarium wilt and charcoal rot resistance screening

Rasha E. Mahdy[1]* and Amer F. Mahmoud[2]

[1] *Agronomy Department, Faculty of Agriculture, Assiut University, 71526 Assiut, Egypt.*
[2] *Department of Plant Pathology, Faculty of Agriculture, Assiut University, 71526 Assiut, Egypt.*

Abstract

Sesame (*Sesame indicum* L.) is being infected with various pathogens which cause severe losses in oil and seed production. This work aimed to identify the most tolerant cultivars to *Fusarium oxysporum* f. sp. *sesami* (Zap) Cast and *Macrophomina phaseolina* (Tassi) Goid, screening of cultivars for agronomic traits and study the path-analysis of yield and its components. Eight cultivars were evaluated in the field and in the green house under artificial infection of both pathogens for the seasons of 2018 and 2019. The combined analysis revealed significant differences among cultivars for most traits. Int 688 was the best cultivar in seed yield/plant (SY/P) under the infection of the two pathogens. The highest correlations were among SY/P, number of seeds/capsule (NS/C), 1000sw and number of capsules/plant (NC/P) at the genotypic level. Generally, the results of path-analysis indicated that both of NS/C and NC/P showed the highest direct and indirect effect on SY/P under the infection both pathogens. It could be concluded that restricted selection by NC/P and NS/C in the segregating generations of crosses among the tolerant parents from these materials could be improve seed yield. The reaction of the eight cultivars to the two pathogens in the green house indicated highly significant differences of susceptibility and resistance to Fusarium wilt and charcoal rot among the tested cultivars. Results indicated that Shandaweel 3, Int 688 and Giza 24 cultivars proved to be the most resistant cultivars; they produce the lowest percentages of disease severity of *Fusarium* wilt and *Macrophomina* damping-off and charcoal rot.

Keywords: *Fusarium oxysporum;* genotypic and phenotypic correlations; *Macrophomina phaseolina*; path coefficient analysis; *Sesame indicum* L.

1. Introduction

Sesame crop (*Sesamum indicum* L.) is one of the oldest oilseed crops known to man. Its cultivation goes back to 2130 B.C. (Weiss, 1983). However, Bedigian and Harlan (1986) noted that it is goes back to 3050-3500 B.C. It is adapted to grow in tropical and sub-tropical areas. The area of sesame cultivation in Egypt tends to decrease due to diseases infections.

***Corresponding author: Rasha Ezzat Mahdy**
Email: rasha.mahdy@aun.edu.eg
Received: March 11, 2022; Accepted: April 10, 2022; Published online: April 12, 2022.

Seed yield is a complex quantitative trait controlled by many genes, and most influenced by fluctuations in environment. So, direct selection for this trait could be misleading. Therefore, plant breeders require the knowledge of the associations between important yield traits and seed yield to identify highly correlated traits with yield as best guide for successful yield improvement by indirect selection. Significant positive correlation of seed yield per plant with days to maturity, number of capsules per plant and 1000 seed weight was noted by Lalpantluangi and Shah (2018). Abate (2018) indicated that number of capsules, biomass yield, days to maturity and harvest index gave maximum positive direct effect on seed yield, suggesting that these traits can be used for selection to improve the primary trait. Eswaran *et al.* (2019) added that 100 seed weight, number of seeds per capsule, capsule length and plant height showed high positive direct effects and significant positive genotypic correlation with seed yield. Gogoi and Sarma (2019) and Aye and Htwe (2019) came to the same conclusion.

Sesame (*Sesame indicum* L.) is being infected with various pathogens which cause severe losses in oilseed production (Zhang *et al.,* 2001). *F. oxysporum* f. sp. *sesami* was reported to be the most economic disease infecting sesame in Egypt and causing severe losses in oilseed production (El-Shazly *et al.,* 1999; EL-Bramawy, 2006; Sahab *et al.,* 2008). Symptoms of Fusarium wilt caused by Fusarium includes wilting of plants, purple bands on stem, extending from base upwards, browning of internal tissue, and always there are conspicuous patches in the severely infected fields (Dong-hua, *et al.,* 2012). *Macrophomina phaseolina* is a soil-borne pathogen that causes charcoal rot disease, of a wide range of cultivated and wild plant species; it has a wide host range and is responsible for causing losses on more than 500 species (Kunwar *et al.,* 1986; Day and MacDonald,1995). *Macrophomina phaseolina* can survive for more than 10 months under dry soil conditions. The severity of the disease is directly related to the population of viable sclerotia in the soil (Khan, 2007). Charcoal rot is a very serious disease on sesame crop especially in Upper Egypt and is one of the most important factors which reduced yield and minimizing the competition of sesame in crop rotation (Abdou *et al.,* 2003; Ahmed *et al.,* 2010). The objectives of this article were to survey eight sesame varieties for seed yield and correlated traits, the associations between important yield traits and seed yield to identify highly correlated traits with yield as best guide for successful yield improvement by indirect selection in crosses of these materials, and identify the tolerant or resistance varieties to Fusarium and charcoal rot diseases.

2. Materials and Methods

Eight cultivars (Table 1) of sesame (*Sesamum indicum* L.) were evaluated for their reaction to *Fusarium oxysporum* f. sp. *sesami* and *Macrophomina phaseolina* (Tassi) Goid in the field and in the green house for two successive seasons of 2018 and 2019 in the Fac. Agric. Res. Farm, Assiut Univ. Egypt.

2.1. Field experiments

In the field the RCBD of three replications for each pathogen was used. The plot was five rows; 4 m long 60 cm apart. Date of planting was April 12th in 2018 and April 15th in 2019. Seeds were dibbled in holes 10 cm within a row and covered with equal amount (approximately 40 g) of pathogen inoculum at the ratio of 1% soil weight. Seedlings were adjusted to 40 seedlings for each row after full emergence. The recommended cultural practices for sesame production were adopted throughout the growing season. The recorded traits were days to 50% flowering (days from planting to the appearance of the first flower in 50% of the plants in a row), plant height (PH, cm), height to the first capsule (HFC, cm), length of the fruiting zone (LFZ, cm = PH-HFC), number of capsules/ plant (NC/ P), seed yield/ plant (SY/P, g), 1000-seed weight, g., capsule length (CL, cm) and capsule width (CW, cm) were measured on 25 capsules for each plot. The severity of the two pathogens was very high. Therefore, the data was recorded on 20 guarded plants in each plot.

2.2. Green house experiments

2.2.1. Isolation and identification of the causal pathogens

Fusarium oxysporum f. sp. *sesami* (Zap) Cast. and *Macrophomina phaseolina* (Tassi) Goid used in this study were isolated from naturally diseased sesame plants showing typical symptoms of wilt and charcoal rot respectively. Diseased samples were collected from Assiut Governorate- Egypt during 2016 growing season. Diseased tissues were cut into small pieces (2-3 mm), washed thoroughly with tap water, the surface was sterilized with 3% sodium hypochlorite (NaOCL) for 3 minutes, washed two times with sterilized water. The sterilized pieces were placed into Petri dishes containing Potato Dextrose Agar (PDA) and incubated at 28±2°C for 3-5 days. Pure cultures of the developing fungi were obtained using single spore and hyphal-tip isolation techniques. Identification of the isolated fungi was carried out on 5-12 days old culture using the morphological and microscopic characteristics of mycelium and spores according to Booth (1971), Domsch *et al*. (1980), Nelson *et al.* (1983), Mahmoud and Budak (2011) and Mahmoud (2016).

Table 1. The cultivars and their origin

Cultivar	origin
Giza 24	Egypt
Giza 25	Egypt
Giza 32	Egypt
Shandaweel 3	Egypt (Giza32x Introduction 130 released in 1992)
Sohag 2000	Egypt (Toshka1xIntroduction 416 released in 1992)
Toshka 1	Egypt (Giza 32 x Introduction 413)
Introduction 688	Imported from Israel in 1988
Introduction 562	Imported from FAO in 1983

2.2.2. Pot experiments

Reactions of eight sesame cultivars for wilt and charcoal rot diseases were evaluated during the two growing seasons (2018 and 2019) in the greenhouse of Plant Pathology Department, Faculty of Agriculture, Assiut University, Egypt. Inocula of the tested pathogens were prepared by growing in sterilized conical flasks (500 ml) containing barley medium (100g barley supplemented, with 2g glucose + 1g yeast extract + 100 ml distilled water) and incubated at 28±2°C for two weeks. Sterilized pots (25 cm in diameter) were filled with sterilized sandy-loam soil which mixed thoroughly with equal amounts of pathogens inoculums at the ratio of 1% soil weight, mixed well and thoroughly irrigated. Soil infestation was carried out one week before sowing seeds to insure establishment and distribution of the inoculums in soil. Each pot was planted with ten surface disinfected seeds. Pots containing 1% non-infested barley medium were used as control treatment. Four pots were used as replicates. The plants were irrigated when necessary and daily observed for infection.

2.2.3. Disease assessment

Wilt disease severity was estimated after 60 days from planting date, as a wilting percentage, on the basis of root discoloration or leaf yellowing using numerical grades ranging from 0 to 5.

0= healthy plants, 1= plants showing chlorosis, 2= 1/3 of sesame plant is wilted, 3= 2/3 of sesame plant is wilted, 4= the whole plant is wilted and 5= dead plants. Disease severity was calculated using the formula described by Mahmoud and Abdalla (2018).

$$\text{Disease severity (\%)} = \frac{\sum[(N\times 0)+(N\times 1)+\ldots\ldots(N\times 5)]}{5T}$$

Where: (N) = the number of plants corresponding to the numerical grade, 0, 1, 2, 3, 4 and 5. (5T) = the total number of plants (T) multiplied by maximum numerical grade (5).

For charcoal-rot, percentages of pre- and post-emergence damping-off were calculated after 15 and 30 days, respectively. At 80 days after sowing, disease severity of charcoal-rot was estimated visually using a numerical grade ranging from (0 to 5) according to *Mahmoud et al.* (2018) as follows:

(0) = No symptoms on plant;

(1) = 1-<10 % area infected; (2) = 10-<25 % area infected; (3) = 25-<50 % area infected; (4) = 50-<75 % area infected; (5) = 75-≤100 % area infected or dead plant.

$$\text{Disease severity} = \frac{\sum[(N\times 0)+(N\times 1)+\ldots.(N\times 5)]}{TN}$$

Where: (TN) = the total number of plants; (N) = number of plants in each group of diseased plants; and (0, 1, 2, ... 5) = numerical grades of diseased plants. The field data were subjected to statistical and separation mean analyses on plot mean basis according to Steel *et al.* (1997). The phenotypic and genotypic correlations between pairs of traits were estimated as Al- Jibouri *et al*. (958). The path coefficient analysis was done as outlined by Dewey and Lu (1959).

3. Results and Discussion

3.1. Field experiments

The analyses of variance in both years and their combined (Tables 2 and 3) revealed significant (p≤ 0.05 or p≤ 0.01) differences among cultivars for all traits except for Cl in the first year and CW in both years under Fusarium infection**,**

Table 2. Mean squares of the studied traits under artificial infection of *Fusarium oxysporum* in separate and combined analysis

Trait	year	Reps	Years (Y)	R/Y	Cultivars (V)	V x Y	Error
50% Flow.	2018	1.04			53.33**		8.28
	2019	0.13			80.19**		0.46
	Comb.		5.33	0.59	87.29**	46.24**	4.37
PH	2018	47.80			1287.14**		14.03
	2019	20.05			614.76**		19.99
	Comb.		221.0**	33.92	1552.50**	349.40**	17.01
HFC	2018	26.54			39.62**		3.35
	2019	7.29			111.14**		16.48
	Comb.		800.33**	16.92	117.24**	33.53**	9.92
LFZ	2018	67.16			1295.76**		14.88
	2019	23.17			383.05**		54.98
	Comb.		1862.53**	45.16	1314.85**	367.94**	34.93
CL	2018	0.04			0.15		0.06
	2019	0.02			0.06**		0.003
	Comb.		0.01	0.03	0.10*	0.11**	0.03
CW	2018	0.004			0.01		0.002
	2019	0.02			0.01		0.002
	Comb.		0.11**	0.01	0.02	0.01	0.01
NC/P	2018	7.55			230.05**		31.14
	2019	4.15			342.02**		26.46
	Comb.		12.94	5.84	479.67**	92.40*	28.80
SY/P	2018	0.86			11.85**		1.31
	2019	0.39			9.62**		0.39
	Comb.		1.26	0.63	18.49**	2.98**	0.85
1000 SW	2018	0.02			0.22**		0.02
	2019	0.014			0.208**		0.011
	Comb.		0.02	0.02	0.40**	0.03	0.02
NS/C	2018	3.64			22.50*		6.02
	2019	9.06			12.04**		2.30
	Comb.		15.59*	5.79	22.53**	7.98*	2.76

* and ** significant at 0.05 and 0.01 levels of probability, respectively, PH=plant height, HFC=height to first capsule, LFZ=length of fruiting zone, Cl=capsule length, CW=capsule width, NC/P=number of capsules/plant, SY/P=seed yield/plant and NS/C=number of seeds/capsule.

Table 3. Mean squares of the studied traits under artificial infection of *Macrophomina phaseolina* (Tassi) Goid in separate and combined analysis

Trait	year	Reps	Years (Y)	R/Y	Cultivars (V)	V x Y	Error
50% Flow.	2018	2.54			72.95**		1.54
	2019	0.50			53.33**		8.31
	Comb.		72.52**	1.52	76.43**	49.85**	4.93
PH	2018	167.05			304.19**		27.04
	2019	1.17			326.99**		26.40
	Comb.		468.75**	84.11	185.71**	445.47**	26.72
HFC	2018	1.50			83.56*		20.26
	2019	2.17			206.45**		13.02
	Comb.		368.52**	1.83	193.73**	96.28**	16.64
LFZ	2018	140.29			213.91*		51.52
	2019	2.00			129.57**		48.62
	Comb.		1668.52**	871.15	95.85	247.62**	50.22
CL	2018	0.01			0.24**		0.012
	2019	0.002			0.281**		0.008
	Comb.		0.06*	0.001	0.47**	0.05**	0.01
CW	2018	0.002			0.01		0.004
	2019	0.002			0.016**		0.003
	Comb.		0.04	0.01	0.02**	0.01	0.005
NC/P	2018	26.22			245.53**		12.48
	2019	1.63			262.28**		25.88
	Comb.		58.28	13.92	416.16**	91.66**	19.10
SY/P	2018	1.58			9.46**		0.725
	2019	0.47			9.78**		0.41
	Comb.		7.42**	1.02	16.71**	2.54**	0.57
1000 SW	2018	0.03			0.19**		0.026
	2019	0.03			0.19**		0.009
	Comb.		0.003	0.03	0.37**	0.01	0.02
NS/C	2018	3.48			13.36*		3.58
	2019	14.62			10.16*		2.69
	Comb.		10.81	9.05*	16.44**	7.08	3.14

* and ** significant at 0.05 and 0.01 levels of probability, respectively, PH=plant height, HFC=height to first capsule, LFZ=length of fruiting zone, Cl=capsule length, CW=capsule width, NC/P=number of capsules/plant, SY/P=seed yield/plant and NS/C=number of seeds/capsule.

and all traits in both years and their combined except for CW in the first year and LFZ in combined analysis under the infection of *M. phaseolina.* The interaction of V × Y was significant for all traits except for CW and 1000 SW under the infection of both pathogen and NS/C under the infection of *M. phaseolina*, indicating different sensitivity of trait to years.

The mean performance of the cultivars from the combined means varied from pathogen to another. Under Fusarium infection (Table 4) days to 50% flowering ranged from 54.17 for Toshka1 to 62.84 for Int.562. Plant height ranged from 99.17 for Sohag 2000 to 142.17cm for Toshka1, HFC from 44.67 to 55.17cm, LFZ from 52.17 to 97.50 cm, NC/P from 70.17 to 104.91, SY/P from 7.73 to 12.91g, 1000SW from 3.56 to 4.15g and NS/C from 28.81to 34.69. Toshka1 was the best for 50% flowering, PH, HFC, and LFZ, and INT.688 was the best for SY/P (12.91g).

Table 4. Mean performance of sesame cultivars for the studied traits under artificial infection of *Fusarium oxysporum* f. sp. sesami (Zap) Cast. in 2018 and 2019 seasons and their combined.

Trait	Year	50%Flo	PH, cm	HFC, cm	LFZ, cm	CL,cm cm	CW,cm cm	NC/P	SY/P,g g	1000S W,g	NS/C
Giza 24	2018	58.00	114.00	44.33	69.67	3.00	0.53	88.33	10.67	3.90	32.17
	2019	50.67	96.67	48.33	48.33	2.60	0.63	76.00	9.28	3.70	30.00
	Comb	54.34	105.33	46.33	59.00	2.80	0.58	82.17	9.98	3.80	31.08
Giza 25	2018	53.33	131.67	45.67	86.00	2.60	0.53	78.33	7.27	3.60	28.35
	2019	46.33	118.00	61.67	56.33	2.57	0.60	80.00	8.20	3.51	29.26
	Comb.	49.83	124.83	53.67	71.17	2.58	0.57	79.17	7.73	3.56	28.81
Giza 32	2018	56.33	130.00	51.67	78.33	3.00	0.60	89.00	9.67	3.87	28.03
	2019	57.33	129.33	58.67	70.67	2.67	0.60	96.00	10.12	3.90	31.24
	Comb.	56.83	129.67	55.17	74.50	2.83	0.60	92.50	9.89	3.88	29.63
Shand aweel 3	2018	55.00	131.67	48.33	83.33	2.60	0.50	103.00	12.03	4.10	33.77
	2019	54.33	138.33	61.00	77.33	2.90	0.70	106.81	13.23	4.20	35.62
	Comb.	54.67	135.00	54.67	80.33	2.75	0.60	104.91	12.63	4.15	34.69
Sohag 2000	2018	53.00	93.33	45.00	48.33	2.53	0.53	90.00	10.80	3.90	32.76
	2019	57.33	105.00	49.00	56.00	2.80	0.63	85.00	9.12	3.70	33.00
	Comb.	55.17	99.17	47.00	52.17	2.67	0.58	87.50	9.96	3.80	32.88
Toshka1	2018	53.00	154.33	40.00	114.33	3.07	0.57	95.00	8.27	3.95	29.22
	2019	55.33	130.00	49.33	80.67	2.97	0.63	102.33	10.83	4.00	31.47
	Comb.	54.17	142.17	44.67	97.50	3.02	0.60	98.67	9.55	3.98	30.34
Int.562	2018	65.67	93.33	41.67	51.67	2.60	0.50	87.04	8.50	3.30	26.33
	2019	60.00	111.00	51.67	59.33	2.83	0.70	88.16	9.38	3.41	31.25
	Comb.	62.84	102.17	46.67	55.50	2.72	0.60	87.60	8.94	3.35	28.79
Int.688	2018	55.00	123.33	44.67	78.67	2.90	0.60	105.00	13.10	4.10	34.23
	2019	62.67	109.00	47.00	62.00	2.80	0.63	93.11	12.72	3.93	30.27
	Comb.	58.84	116.17	45.83	70.33	2.85	0.62	99.06	12.91	4.02	32.25
LSD 0.05	2018	5.03	6.54	3.27	6.74	ns	ns	9.75	1.99	0.26	4.29
LSD 0.01		7.00	9.11	4.55	9.39	ns	ns	13.58	2.78	0.37	5.97
LSD 0.05	2019	1.18	7.81	7.09	12.96	0.10	0.08	8.99	1.10	0.18	2.65
LSD 0.01		1.65	10.88	9.88	18.04	0.13	0.11	12.52	1.53	0.26	3.70
LSD 0.05	comb.	2.47	4.88	3.73	6.99	0.20	ns	6.35	1.09	0.17	1.97
LSD 0.01		3.33	6.57	5.02	9.42	0.28	ns	8.55	1.47	0.22	2.65

ns= not significant, PH=plant height, HFC=height to first capsule, LFZ=length of fruiting zone, Cl=capsule length, CW=capsule width, NC/P=number of capsules/plant, SY/P=seed yield/plant and NS/C=number of seeds/capsule.

Under infection of *Macrophomina* (Table 5) the traits ranged from 50.0 to 61.0 for days to 50% flowering, 95.83 to 112.83cm for PH, 36.67 to 56.67 cm for HFC, 55.83 to 68.00 cm for LFZ,82.5 to 106.07 for NC/P, 7.87 to 12.73 g for SY/P, 3.40 to 4.13g for 1000 SW and 28.55 to 33.96 for NS/C. Sohag 2000 was the best cultivar for earliness, PH and LFZ, while INT. 688 was the best in SY/P (12.73g) followed by Shandaweel 3(12.33g). It could be noticed that Shandaweel 3 carried the favorable characters under both pathogens infection except 50% flowering under the infection of *Macrophomina*.

Table 5. Mean performance of sesame cultivars for the studied traits under artificial infection of *Macrophomina phaseolina* (Tassi) Goid in 2018 and 2019 seasons and their combined.

Trait		50%	PH,cm	HFC,	LFZ,	CL,	CW,	NC/P	SY/P,	1000SW,	NS/C
Giza 24	2018	52.00	115.00	42.33	72.67	2.63	0.53	88.33	10.17	3.80	31.67
	2019	56.00	99.33	45.00	54.33	2.53	0.60	79.33	9.27	3.77	30.33
	Comb.	54.00	107.17	43.67	63.50	2.58	0.57	83.83	9.72	3.78	31.00
Giza 25	2018	54.00	130.00	50.00	80.00	2.53	0.67	81.67	7.13	3.53	27.83
	2019	54.00	94.67	48.33	46.33	2.60	0.73	83.33	8.60	3.51	29.26
	Comb.	54.00	112.33	49.17	63.17	2.57	0.70	82.50	7.87	3.52	28.55
Giza 32	2018	53.00	120.00	39.67	80.33	3.10	0.70	94.00	9.37	3.80	28.67
	2019	56.33	105.67	50.00	55.67	3.20	0.77	97.33	9.97	3.87	31.24
	Comb.	54.67	112.83	44.83	68.00	3.15	0.73	95.67	9.67	3.83	29.95
Shand aweel 3	2018	65.00	110.00	50.00	60.00	2.57	0.70	105.33	11.43	4.07	32.30
	2019	57.00	115.00	63.33	51.67	3.03	0.77	106.81	13.23	4.20	35.62
	Comb.	61.00	112.50	56.67	55.83	2.80	0.73	106.07	12.33	4.13	33.96
Sohag 2000	2018	48.00	101.67	40.00	61.67	2.53	0.60	91.67	10.23	3.73	32.50
	2019	52.00	90.00	33.33	56.67	2.47	0.63	85.00	9.12	3.70	31.67
	Comb.	50.00	95.83	36.67	59.17	2.50	0.62	88.33	9.68	3.72	32.08
Toshki	2018	53.00	111.67	48.33	63.33	3.23	0.60	95.00	8.10	3.88	29.30
	2019	53.00	103.33	48.33	55.00	3.20	0.73	100.67	10.83	3.87	31.80
	Comb.	53.00	107.50	48.33	59.17	3.22	0.67	97.83	9.47	3.88	30.55
Int.562	2018	53.00	100.67	40.00	60.67	2.50	0.63	87.04	8.33	3.40	29.10
	2019	65.67	116.67	51.00	65.67	2.57	0.63	89.82	9.38	3.41	31.52
	Comb.	59.33	108.67	45.50	63.17	2.53	0.63	88.43	8.86	3.40	30.31
Int.688	2018	51.33	103.33	36.67	66.67	2.67	0.60	108.33	12.43	4.17	29.10
	2019	55.00	117.67	52.00	65.67	2.73	0.60	91.44	13.09	3.97	31.52
	Comb.	53.17	110.50	44.33	66.17	2.70	0.60	99.89	12.76	4.07	30.31
LSD .05	2018	2.16	53.37	7.86	12.58	0.19	ns	6.17	1.49	0.28	3.30
LSD .01		3.02	74.32	10.95	17.51	0.27	ns	8.59	2.07	0.39	4.6
LSD .05	2019	5.04	8.98	6.30	12.18	0.16	0.10	8.89	1.12	0.16	2.87
LSD .01		7.01	12.50	8.78	16.96	0.22	0.13	12.38	1.56	0.23	3.99
LSD .05	comb.	2.47	4.88	3.73	6.99	0.20	ns	6.35	1.09	0.17	1.97
LSD .01		3.33	6.57	5.02	9.42	0.28	ns	8.55	1.47	0.22	2.65

ns= not significant, PH=plant height, HFC=height to first capsule, LFZ=length of fruiting zone, Cl=capsule length, CW=capsule width, NC/P=number of capsules/plant, SY/P=seed yield/plant and NS/C=number of seeds/capsule.

3.2. Phenotypic and genotypic correlations

Study the correlation coefficients among the contributing traits of SY/P provides a reliable measure of associations useful in sesame breeding for seed yield. The genotypic and phenotypic correlations based on the combined data among SY/P and its contributing traits (NC/P, NS/C and 1000 SW) are shown in Table 6 for the two pathogens. The highest correlation with SY/P was for NS/C followed by 1000SW and NC/P at genotypic level, and the lowest one was between NS/C and NC/P. These results are in line of those reported by Aye and Htwe (2019), Eswaran *et al*. (2019) and Gogoi and Sarma (2019).

Table 6. Phenotypic (r_{ph}) (above) and genotypic (r_g) correlation coefficients among traits under artificial infection of *Fusarium* and *Macrophomina* based on the combined data of the two seasons

	Fusarium oxysporum f. sp. *sesami* (Zap) Cast				*Macrophomina phaseolina* (Tassi) Goid			
	1	2	3	4	1	2	3	4
1-SY/P		0.7877	0.8357	0.7538		0.7994	0.8536	0.8799
2-NC/P	0.7858		0.6994	0.7482	0.8462		0.6855	0.8333
3-NS/C	0.9586	0.6625		0.7417	0.9798	0.5912		0.7399
4-1000SW	0.7864	0.7927	0.7417		0.9567	0.8660	0.8498	

SY/P=seed yield/plant, NC/P=number of capsules/plant, and NS/C=number of seeds/capsule.

3.3. Path - coefficient analysis of the first set of varieties

Path - coefficient analysis facilitates the understanding of the cause and effect system in the form of direct and indirect effects of characters on the dependent variable; seed yield. Study of path-coefficient enable the breeder to identify few characters of high direct effects on seed yield. This helps the breeder to restrict selection for few important traits and reduce time and effort. The genotypic and phenotypic correlation coefficients of SY/P with its contributing traits were partitioned to direct and indirect effects (Table 7). Partitioning the correlation coefficients of NC/P, NS/C and 1000SW with SY/P to their direct and indirect effects indicated that the direct effect of NS/C was the highest followed by NC/P. However, the direct effect of 1000SW on SY/P was negative or negligible on genotypic and phenotypic levels under infection of both pathogens. This could be due to the variation of 1000SW among the studied cultivars was low. Generally, the results indicate that the direct and indirect effects of NS/C on SY/P were larger than that of NC/P either on the genotypic or phenotypic level under both pathogens infection.

Table 7. Direct and indirect effects based on phenotypic and genotypic correlations of number of capsules/P(NC/P), number of seeds/capsule (NS/C) and 1000seed weight (1000 SW) with seed yield/P (SY/P) under artificial infection of *Fusarium* and *Macrophomina phaseolina* for 8 varieties of sesame over two seasons.

Effect	*Fusarium* infection		*Macrophomina* infection	
	Phenotypic	Genotypic	Phenotypic	Genotypic
Correlation between NC/P and SY/P	0.7877	0.7858	0.7994	0.8462
Direct effect of NC/P	0.3425	0.4459	0.1196	0.5996
Indirect effect via NS/C	0.3531	0.6736	0.2943	0.5397
Indirect effect via 1000 SW	0.0921	-0.3336	0.3855	-0.2931
Total effect	0.7877	0.7858	0.7994	0.8462
Correlation between NS/C and SY/P	0.8357	0.9586	0.8536	0.9798
Direct effect of NS/C	0.5048	1.016636	0.4293	0.9130
Indirect effect via NC/P	0.2396	0.2954	0.0820	0.3545
Indirect effect via 1000 SW	0.0913	-0.3534	0.3422	-0.2876
Total effect	0.8357	0.9586	0.8536	0.9798
Correlation between 1000 Sw and SY/P	0.7538	0.7864	0.8799	0.9567
Direct effect of 1000SW	0.1231	-0.4209	0.4625	-0.3384
Indirect effect via NC/P	0.2563	0.3535	0.0997	0.5193
Indirect effect via NS/C	0.3744	0.8538	0.3177	0.7759
Total effect	0.7538	0.7864	0.8799	0.9567
Residual effect	0.4643	0.0772	0.3619	0.0781

Aremu *et al*. (2011) and Ibrahim *et al*. (2012) noted that that number of capsules / plants, 1000-seed weight and number of seeds/capsules had the highest positive direct effects on seed yield/plant. Eswaran *et al.* (2019) studied the causal and effect system and indicated that 100 seed weight, number of seeds per capsule, capsule length and plant height were the most yield attributes at the genotypic level. It could be concluded that restrict selection for NC/P and NS/C in the segregating generation of crosses among these materials could improve seed yield.

3.4. Pots experiments

Obtained data of this study showed significant variation in responsiveness among sesame cultivars to Fusarium wilt and charcoal rot diseases under greenhouse conditions during two growing seasons (2018 and 2019). No symptoms were observed in non-inoculated plants (control).

Results presented in Table 8 showed that all tested sesame cultivars were susceptible to infection by *F. oxysporum* f.sp. *sesami*. Wilt symptoms were occurred in the most of tested sesame cultivars. The percentages average of disease severity was differed from cultivar to another and ranged from 38.37% to 92.37%. Sesame cultivars varied significantly in their reaction to infection. Shandaweel 3, Int 688 and Giza 24 proved to be the most resistant cultivars; they produce the lowest percentages of disease severity (38.37%, 49.87% and 50.50% respectively). Giza 32, Sohag 2000 and Giza 25 were very susceptible cultivars, and produced the highest percentages average of disease severity (92.37%, 90.00% and 84.12% respectively). While, other tested cultivars showed intermediate reactions.

Table 8. Screening for resistance to Fusarium wilt caused by *F. oxysporum* in sesame cultivars under greenhouse conditions during 2018 and 2019 growing seasons

Cultivar / Cultivars	Disease severity (%)		
	2018 season	2019 season	Average
Toshka 1	64.25	63.00	63.62
Shandaweel 3	39.50	37.25	38.37
Giza 24	53.00	48.00	50.50
Int 562	65.25	67.25	66.25
Giza 25	84.50	83.75	84.12
Sohag 2000	91.00	89.00	90.00
Int 688	52.75	47.00	49.87
Giza 32	92.75	92.00	92.37
$LSD_{0.05}$	5.7	3.9	-

Data presented in Table 9 revealed that, all evaluated sesame cultivars showed susceptible reaction to *M. phaseolina*. Whereas, sesame cultivars Shandaweel 3 and Int 688 proved to be the most resistant cultivars against *M. phaseolina* infestation, they produced surviving plants at rate more than 55% and disease severity less than 3.75. While, sesame cultivars Giza 25 and Giza 32 proved to be very susceptible to *M. phaseolina*, they produced surviving plants at rate less than 33% and disease severity more than 4.2. Other tested cultivars (Sohag 2000, Int 562, Giza 24, and Toshka 1) showed moderate reactions, they produced surviving plants at rate of 41.25% to 48.75% and disease severity of 4, 3.94 to 3.75 and 3.77 respectively.

Table 9. Screening for resistance to charcoal rot caused by *M. phaseolina* in sesame cultivars under greenhouse conditions during 2017 and 2018 growing seasons.

Cultivars	Damping-off (%)						Survival plants (%)			Charcoal rot severity		
	Pre- emergence			Post- emergence								
	2018	2019	Average	2018	2019	Average	2018	2019	Average	2018	2019	Average
Toshka 1	47.5	40.0	43.75	05.0	10.0	07.5	47.5	50.0	48.75	3.80	3.75	3.77
Shandaweel 3	30.0	17.5	23.75	12.5	07.5	10.0	57.5	75.0	66.25	3.61	3.16	3.38
Giza 24	47.5	30.0	38.75	12.5	12.5	12.5	40.0	57.5	48.75	3.98	3.53	3.75
Int.562	55.0	35.0	45.00	12.5	07.5	10.0	32.5	57.5	45.00	4.25	3.63	3.94
Giza 25	62.5	37.5	50.00	20.0	15.0	17.5	17.5	47.5	32.50	4.59	3.84	4.21
Sohag 2000	60.0	40.0	50.00	05.0	12.5	8.75	35.0	47.5	41.25	4.17	3.84	4.00
Int.688	47.5	25.0	36.25	07.5	10.0	8.75	45.0	65.0	55.00	3.90	3.34	3.62
Giza 32	72.5	42.5	57.50	07.5	12.5	10.0	20.0	45.0	32.50	4.56	3.89	4.22
$LSD_{0.05}$	14.1	11.98	-	11	7.72	-	12.9	13.94	-	0.54	0.81	-

4. Conclusion

It could be concluded that Shandaweel 3, Int 688 and Giza 24 cultivars proved to be the most resistant cultivars; they produce the lowest percentages of disease severity of Fusarium wilt and *Macrophomina* damping-off and charcoal rot.

Authors' Contributions
All authors are contributed in this research.
Funding
There is no fund in this research.
Institutional Review Board Statement
All Institutional Review Board Statement are confirmed and approved.
Data Availability Statement
Data presented in this study are available on fair request from the respective author.
Ethics Approval and Consent to Participate
This work carried out at department of agronomy and department of plant Pathology Plant Pathology and followed all the departments instructions.
Consent for Publication
Not applicable.
Conflicts of Interest
The authors declare no conflict of interest.

5. References

Abate, M. (2018). 'correlation and path coefficient analysis in mid-altitude sesame (*Sesamum indicum* L.) germplasm collection of Ethiopia', *Comparative study of M. oleifera and M. ovalifolia survival rates in Central Namibia*, pp. 1–7. doi: 10.24966/pscr-3743/100006.

Abdou, E., Abd-Alla, H.M., Galal, A.A. (2003). 'Survey of sesame root rot/ wilt disease in Minia and their possible control by ascorbic and salicylic acids', *Assiut J. Agric. Sci.*, 32, pp. 135–152.

Ahmed, H.A.M., Abdel-Razik, A.A., Hassan, M.H.A., Khaled, S.A. (2010). 'Management of charcoal rot of sesame by seed soaking in medicinal plant extracts and hot water', *Plant Pathology Journal*, 26(4), pp. 372–379. doi: 10.5423/PPJ.2010.26.4.372.

Al- Jibouri, H.A., Miller, P.A., Robinson, H.F. (1958). ' Genotypic and environmental variances and covariances in an Upland cotton cross of interspecific origin', *Agronomy Journal*, 50(10), pp. 633–636. doi: 10.2134/agronj1958.00021962005000100020x.

Aremu, C.O., Adewale, D.B., Adetunji, I.A. (2011). 'Cause and effect variations and trait selection index for indigenous sesame (*Sesamum indicum*) genotypes', *International Journal of Applied Agricultural and Apicultural Research*, 7, pp. 64–71.

Aye, M., Htwe, N.M. (2019). 'Trait association and path coefficient analysis for yield traits in myanmar sesame (*Sesamum indicum* l.) germplasm', *Journal of Experimental Agriculture International*, 41(3), pp. 1–10. doi: 10.9734/jeai/2019/v41i330402.

Bedigian, D., Harlan, J.R. (1986). 'Evidence for cultivation of sesame in the ancient world', *Econ. Bot.* 40, pp. 137–154.

Booth, C. (1971). '*The genus Fusarium*'. Commonwealth Mycological Institute, Kew, Surrey, England.

Day, J.P. , MacDonald, M.V. (1995). 'Plant-pathogen interactions of sunflower and Macrophomina phaseolina in vitro and in vivo', *Plant Pathology*, 44, pp. 261–269.

Dewey, D.R., Lu, K.H. (1959). 'A correlation and path- coefficient analysis of components of crested wheatgrass seed production', *Agronomy Journal*, 51(9), pp. 515–518. doi: 10.2134/agronj1959.00021962005100090002x.

Domsch, K.H., Gams, W., Anderson, T.H. (1980). '*Compendium of Soil Fungi*', Academic Press. A Subsidiary of Harcourt Brace Jovanovich, Publishers, London, pp. 1- 859.

Dong-Hua, Li., Lin-Hai, W., Yan-Xin, Z., Hai-xia, L., Xiao-Qiong, Q., Wen-Liang, W., Xiu-Rong, Z. (2012). 'Pathogenic variation and molecular characterization of Fusarium species isolated from wilted sesame in China', *African Journal of Microbiology Research*, 6(1), pp. 149–154. doi: 10.5897/AJMR11.1081.

EL-BRAMAWY, M.A.S. (2006). 'Inheritance of resistance to fusarium wilt in some sesame crosses under field conditions', *Plant Protect. Sci.*, 42, No. 3:(3), pp. 99–105.

El-Shazly, M.S., El-Ashry, M.A., Ammar, S.M., El-Bramawy, M.A.S. (1999). 'Evaluation of resistance to fusarium wilt disease in sesame germplasm', *International Journal of Pest Management*, 45(3), pp. 207–210. doi: 10.1080/096708799227806.

Eswaran, R., Karthikeyan, P., Venkatesan, M., Elangaimannan, R., Thangavel, P. (2019). 'Association analysis in sesame (*Sesamum indicum* L.)', *Journal of Pharmacognosy and Phytochemistry* ., SP2, pp. 18–19.

Gogoi, L.R., Sarma, R.N. (2019). 'Variability and path coefficient analysis in sesame (*Sesamum indicum* L.)', *International Journal of Current Microbiology and Applied Sciences*, 8(07), pp. 229–237. doi: 10.20546/ijcmas.2019.807.029.

Ibhrahim, E., Khidir, O. (2012). 'Genotypic correlation and path coefficient analysis of yield and some yield components in sesame (*Sesamum indicum* L.)', *International Academic Journals International Journal of AgriScience*, 2(8), pp. 664–670. Available at: www.inacj.com.

Khan, S.N. (2007). 'Macrophomina phaseolina as causal agent for charcoal rot of sunflower', *Mycopath*, (5), pp. 111–118.

Kunwar, I.K. (1986). 'Histopathology of soybean seed and seedling infection by *Macrophomina phaseolina* ', *Phytopathology*, pp. 532. doi: 10.1094/phyto-76-532.

Lalpantluangi, P.C., Shah, P. (2018). 'Character association and path coefficient analysis in sesame (*Sesamum indicum* L.) genotypes under foothill condition of Nagaland', *The Pharma Innovation Journal*, 7(5), pp. 82–87. Available at: www.thepharmajournal.com.

Mahmoud A., Budak, H. (2011). 'First report of charcoal rot caused by Macrophomina phaseolina in sunflower in Turkey', *Plant Disease*, 95(2), p. 223.

Mahmoud, A.F. (2016). 'Occurrence of Fusarium wilt on summer squash caused by *Fusarium oxysporum* in Assiut, Egypt', *Journal of Phytopathology and Pest Management*, 3(1), pp. 34–45.

Mahmoud, A.F., Abdalla, O.A. (2018). 'Biocontrol efficacy of Trichoderma spp. against sesame wilt caused by *Fusarium oxysporum* f. sp. sesami', *Archives of Phytopathology and Plant Protection*, 51(5–6), pp. 277–287. doi: 10.1080/03235408.2018.1471837.

Mahmoud, A.F., Abou-Elwafa, S.F., Shehzad, T.

(2018). ‘Identification of charcoal rot resistance QTLs in sorghum using association and in silico analyses’, *Journal of Applied Genetics*, 59(3), pp. 243–251. doi: 10.1007/s13353-018-0446-5.

Nelson, P.E., Toussoun, T.A., Marasas, W.F. (1983). ‘*Fusarium species: an illustrated manual for identification*’, University Park: Pennsylvania State University Press, pp. 206.

Sahab, A.F., Elewa, I.S., Mostafa, M.H., Ziedan, E.H. (2008). ‘Morphological, physiological and pathological investigation on *Fusarium oxysporum* f.sp. sesame.’, *Egypt journal of Agriculture Research*, 1, pp. 167–181.

Steel, R.G.D., Torrie, J.H., Dicky, D.A. (1997). ‘*Principles and Procedures of Statistics, A Biometrical Approach*’, 3rd Edition, McGraw Hill, Inc. Book Co., ...

Weiss, E.A. (1983). *‘sesame.oilseed crops’,* Longman Group, New York. pp. 282-340.