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Effect of *Verticillium dahliae* Kleb. on cotton yield and fiber technological properties

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Abstract

The objective of this study was to determine the effect of *Verticillium dahliae* Kleb. on cotton yield and fiber technological properties, relationships among to disease and seed cotton yield, fiber yield and fiber technological properties and also determine susceptible and tolerant cotton varieties. The study was conducted in the Southeastern Anatolia Agricultural Research Institute's experimental area during 2004-2006. The experiment was arranged as a randomized split block design with four replications. Main plot consisted of infected and non-infected area, sub-plot consisted of varieties. In this study 10 different commercial cotton varieties were grown to test the v*erticillium* wilt performance. The results indicated that there were significant differences among varieties for all of the investigated characteristics. Area differences were significant for all of the investigated traits except ginning percentage. The results of the non-infected area showed that there were decreasing with regard to foliar disease index (FDI), vascular disease index (VDI), vascular disease rate (VDR), first picking percentage, fiber fineness, micronaire and yellowness; while increasing with regard to seed cotton yield, fiber yield, fiber length, strength, elongation, uniformity, reflectance and spinning consistecy index. Only ginning percentage was unaffected from area differences. With planting cotton varieties in non-infected area there were 323.60 kg ha^{-1} increase for seed cotton yield and 114.50 kg ha^{-1} for lint yield. Disease led to a decrease (7.86%) in seed cotton yield and (6.73%) in fiber yield. The results of this study indicated that GW-Teks, GW-Golda and Carmen varieties were tolerant; while Maraş 92, Sayar 314 and Stoneville 453 were sensitive in terms of FDI, VDI and VDR and tolerant varieties can be used as parents in *Verticillium* breeding programs.

Keywords: Cotton; Wilt; *Verticillium dahliae*; Yield; Technological properties; Disease rate; Disease severity.

Introduction

Verticillium wilt of cotton is caused by *Verticillium dahliae* Kleb. a soil borne fungus that enters the roots and grows into the vascular system of the plant. Symptoms of infection appear as necrotic areas on leaves wilting and usually discoloration of the vascular tissue. Severely affected plants shed all their leaves and most of their young bolls. The cotiledons of infected cotton plants become yellowish and quickly dry out. Young plants with three to five true leaves suffer considerable stunting. The leaves appear darker green than those of a normal plant and become somewhat crinkled between the veins (Presley, 1953). The amount of stunting apparently depends on the stage of development of the plant when it becames infected. The outstanding symptom is the chloritic areas on the leaf margins and between the principal veins, which make it look mottled (Presley, 1953). Plants may lose their leaves if infected with a defoliating strain of the fungus. *V. dahliae* fungus causes diseases in many crops such as vegetables, leguminous plants, ornamentals, industrial plants, orchards and wild plants besides cotton plant. If plants wilt and die, foliar symptoms may be confused with those of cotton root, but plants infected with *Verticillium* only have no rotten roots (URL-1).

Weather and cultural conditions that generally favour more severe occurrences of *Verticillium wilt include prolonged periods of cool, wet weather, cool weather with frequent, irrigation and cultural practices that encourage rank growth and delayed maturity*. No single method is effective in controlling the disease, but an integrated management system is necessary to minimize losses (El-Zik, 1985). The selection of resistant or tolerant cultivars (Shen, 1985) and the application appropriate cultural practices are recommended to control of the diseases (Minton et al., 1972; Frisbie et al., 1989; Melero-Vara et al., 1995; Sagır and Basbag, 2002; URL-2; Newman, 2007).

Verticillium dahliae Kleb. is a major constraint to cotton production in almost all countries. It was first recorded on cotton in the Manisa province of the Aegean region of Turkey in 1941 (Iyriboz, 1941), but was not identified as an important disease under field conditions until 1967. Later Karaca et al., 1971 indicated that the disease was common in the Aegean and Mediterranean regions. Sagır et al. (1995), reported that *Verticillium wilt* is one of the most important disease with 79.28% prevalence rate and 16.27% mean disease rate in the Southeastern Anatolia Region's cotton planted area.

V. dahliae isolates infecting cotton can be classified into D (defoliating) and ND (nondefoliating) pathotypes, based on their ability to cause defoliation or not of leaves from shoots (Bejarano-Alcazar et al., 1997).

Both of the pathotypes of *V. dahliae* have been existing in Turkey cotton planted areas (Göre et al., 2007). It was found that the most commonly cultivated cultivars in Turkey were more susceptible to the D pathotype than the ND pathotype. (Göre et al., 2009).

It's known that most of the commercial varieties of upland cotton appear to be susceptible to verticillium wilts than the other species as compared Pima, Sea-Island and *G. Barbadense* (Presley, 1953; Azaddisfani and Zangi, 2007). Despite the extreme succeptibility of most commercial upland varieties, some progress has been made through selection and breeding toward a high degree of tolerance or resistance. Erdogan et al., 2006, screened cotton cultivars resistance to the disease and they found the Carmen as superior variety for yield and fiber guality in infected area. Kechagia and Xanthopoulos (1998) reported that fibers from the highest degree applies (degrees from 0 to 4; 0 shows plants completely lacking symptoms of the disease and 4 is totaly wilted plants) are seriously damaged in all cultivars and therefore cannot be use for spinning because they are below the spinnable limits.

The objective of this study was to determine the effect of *Verticillium dahliae* Kleb. on cotton yield and fiber technological properties, relationships among to disease and seed cotton yield, fiber yield and fiber technological properties and also susceptible and tolerant cotton varieties.

Materials and Methods

Plant Material and Experimental Design

This study was conducted during three cotton growing season over the 2004-2006 periods in the experimental field of Southeastern Anatolia Agricultural Research Institute in Diyarbakır province ecological conditions of the Southeastern Anatolia Region of Turkey.

The experiments were arranged as a randomized split block design with four replications. Main plot consisted of infected and non-infected areas, sub-plot consisted of varieties. In this study 10 different cotton varieties (*Gossypium hirsutum* L.) including check varieties (Carmen as tolerant and Sayar 314 as succeptible) were grown in two different area to test the

v*erticillium* wilt performance of varieties. One of the main-plot was naturally infected area with v*erticillium* wilt while other main-plot was non-infected and crop rotations implemented. Each sub-plot was consisted of four rows of 12 m length, between and within the row spacing were 70 cm and 20-25 cm respectively.

Sowing was made with combine cotton drilling machine. Seeds were planted at first year on 29 April, second year on 27 April and third year on 10 May; and all plots were treated with 20-20-0 composite fertilizer to provide 70 kg ha^{-1} N and 70 kg ha^{-1} P_2O_5. Just before the flowering, 70 kg ha^{-1} N (as ammonium nitrate) was applied to the trial as an additional N source. The experiment was thinned and hoed three times by hand and four times with machine only once herbicide was used before sowing in all the three years. Insect control was needed for (*Aphis gossypi*) and leaf fleahopper (*Empoasca spp*.) in 2004; Thiodan (2000 cc/ha) was applied two times in one growing season. Another two year insects were monitored throughout the experiment and decided that no insect control was necessary during growing season. Experimental plots were irrigated for the first time five weeks after sowing, and repeatedly eight times at ten or twelve-day intervals. Furrow irrigation was applied all the three years. Plots were harvested twice by hand and seed cotton yield of four rows of plot were weighted and calculated for first picking percentage. After harvesting seed cotton samples were ginned on a laboratory roller-gin for lint percentage. Fiber samples were analyzed for fiber guality properties by HVI Spectrum at the Nazilli Cotton Research Institute's cotton fiber laboratory.

Data collection and statistical analysis

Observation of diseases were taken from middle two rows of the plot on leaves of consecutive 30 plants at 50% boll opening stage and stems following the last harvesting by hand. 0-3 scale (0, healhty plants, 1, 1-33%; 2, 34-67%, 3, 68-100%) was used for observations of diseases (Barrow, 1970; Erwin et al., 1976), besides discoloration of the interior of the stems were taken into account and plants marked as healthy or diseased. After this observation; number of infected plants divided to number of totally observed plants. So, disease rates calculated and obtained data subjected to Arcsin for transformation (Karman, 1971) and JMP 5.0.1 statistical software program were used for evaluating of all data and differences were tested for significance using $LSD_{(0.05)}$.

Field Site

The soils of the experimental area were zonal soils which are generally red-brown and included in the big soil group having a clayish nature, flat or about-to-be flat, having very small erosion and deep or medium deep. The soil is low in organic material and phosphorus, has adequate calcium and high clay content (49-67%) in the 0-150 cm profile.

Trials were conducted on a loamy-clay soil at pH 7.7 and lime content of 7.2 without salinity problem. Soil samples were taken 0-30 cm deeper from soil surface for soil analysis. Some of the pysical and chemical characteristics of infected area and non-infected area were presented in Table 1. It can be seen that on Table 1, soil samples of infected area and non-infected area were similar for saturation, pH, lime, phosphorus, potassium and organic matter content. *Verticillium wilt* inoculum density was determined as 16.3 CFU (microsclerotia/g) in soil in infected area and 1.2 CFU (microsclerotia/g) in soil in non-infected area according to (Melouk, 1992).

Table 1. Some of physical and chemical characteristics of experimental field.

Area	Structure	Saturation (%)	pH	Lime $CaCO_3$	Phosphorus P_2O_5	Potassium K_2O	Organic matter
Infected area	Loamy-clay	1.82		40	3.1	7.2	7.7 63
Non-infected area	Loamy-clay	1.97		39	3.7	6.7	7.8 65

Source: Southeastern Anatolia Agricultural Research Institute's Laboratory Results, 2004. Diyarbakır.

Climatical Conditions

In the Southeastern Anatolia of Turkey, long years climatically findings showed that there were 491 mm total rainfall and 15.8 ºC average temperature. The average maximum temperature can reach 38.3 ºC in July. During the investigation the meteorological data were recorded from planting date to harvest date and presented on Table 2. It can be seen that total rainfall in May 2004, June 2004 and 2005 was over the long term periods, but it was not observed rainfall in the July and August in 2004 and 2005.

Table 2. Mean of temperature, maximum temperature and total rainfall during the investigation and long term period.

Months	Mean Temperature (ºC)				Maximum Temperature (ºC)				Total Rainfall (mm)			
	2004	2005	2006	Long Term	2004	2005	2006	Long Term	2004	2005	2006	Long Term
March	9.6	8.4	9.2	8.2	17.0	14.0	15.9	14.2	1.5	58.4	26.6	67.9
April	12.8	14.1	14.5	13.8	20.1	21.1	20.6	20.3	54.9	36.8	77.9	70.5
May	18.0	19.6	19.4	19.2	25.3	27.5	27.5	26.5	97.5	26.5	38.4	42.1
June	26.4	25.8	28.5	26.0	33.8	33.1	37.0	33.3	16.0	33.1	-	6.9
July	31.1	32.4	31.4	31.0	38.2	39.7	38.1	38.3	-	-	6.1	0.6
August	30.0	31.8	32.6	30.3	37.5	39.2	40.9	38.0	-	-	-	0.4
September	25.0	25.0	25.0	24.8	34.0	32.8	33.1	33.2	-	0.7	3.5	2.7
October	18.2	16.2	17.6	17.1	26.7	24.7	25.1	25.2	1.3	14.9	104.5	31.1

Source: Turkish State Meteorological Service, Diyarbakır.

Results

Results from the analysis of variance for observed characteristics in the experiment are presented in Table 3. It can be seen that differences of variety were significant at (P>0.01) probability level for all the investigated traits; year differences were significant for all the investigated traits except ginning percentage and fiber elongation. Area differences were significant for foliar disease index, vascular disease index, vascular disease rate, first picking percentage, seed cotton yield, fiber length, fineness, strength, üniformity, yellowness and spinning consistency index but not for ginning percentage.

The mean values of observed traits for varieties, years, area and significant interactions were presented in Table 4-8 Year, area and variety differences were significant for foliar disease index (Table 3). Foliar disease index (FDI) was found 0.87 in infected area and 0.61 in non-infected area. Variety differences were also significant. In these varieties FDI were ranged from 0.40 to 1.08 (Table 4). GW-Teks, Carmen and GW-Golda varieties had the lowest FDI, while Sayar 314 and Maraş 92 varieties had the highest value. The other cotton varieties used in the experiment were determined in moderate tolerance level for foliar disease index. Year×variety interaction was significant; the highest FDI was obtained from Stoneville 453 in 2005, but the lowest value was obtained from Carmen variety in 2004.

Table 3. Analysis of variance for investigated characters and mean of square values.

Source of variances	df	FDI	VDI	VDR	FPP	GP	SCY	FY	FL	FF	FS	ELG	UNF	R	+b	SCI
Year (Y)	2	5.25**	6.93**	7268.8**	7437.4**	32.57	56761.3*	8938.51*	15.16**	4.13**	27.68**	0.63	16.38**	395.66**	4.50**	2390.62**
Replication [Year]	9	0.17	0.28**	469.81**	71.67	20.75	4530.1	1007.38	0.54	0.21	2.54	0.32	1.07	5.54	0.09	133.06
Area (A)	1	3.95**	4.12**	6235.16**	2688.82**	13.63	62810.4*	7865.98*	20.16**	4.76**	62.83**	0.71*	7.10*	28.22*	3.87**	4628.82**
Year × Area	2	0.14	0.21*	1142.87**	419.61*	4.85	58392.9*	8283.48	1.07	0.59	3.11	0.34	1.26	50.78*	0.70*	134.81
Rep × Area [Year] and Random	9	0.05	0.03	43.15	80.11**	18.29**	99742**	2251.89**	0.33	0.30	1.48	0.17	1.08	7.86*	0.12	70.45
Variety (V)	9	1.20**	0.56**	793.39**	1491.45**	31.82**	11008.7**	1839.4**	6.04**	0.81**	151.83**	6.66**	12.36**	28.88**	0.40**	3347.76**
Year × Variety	18	0.21**	0.23**	285.23**	127.31**	5.15	4346.74**	973.51**	1.28*	0.27	6.04**	0.42**	1.60	6.43*	0.25**	248.82**
Area × Variety	9	0.01	0.08	163.48	50.98	4.00	5055.77**	947.96**	0.27	0.13	2.44	0.19	1.97	2.10	0.06	69.12
Year×Area×Variety	18	0.02	0.06	163.30*	17.10	5.46	796.62	230.74	0.43	0.14	1.32	0.05	1.72	3.32	0.08	110.99
Error	162	0.03	0.05	95.28	29.48	6.01	1444.23	319.17	0.66	0.16	2.83	0.11	1.06	3.31	0.08	120.26
Total	239															

*, ** Significant at 0.05 and 0.01 level of probability, respectively.

FDI=Foliar desease index, VDI=Vascular disease index, VDR=Vascular disease rate, FPP=First Picking Percentage, GP=Ginning percentage, SCY=Seed cotton yield, FY=Fiber yield, FL=Fiber length, FF=Fiber fineness, FS=Fiber strength, ELG=Elongation, UNF=Uniformity, R=Reflectance, +b=Yellowness, SCI=Spinning consistency index.

Table 4. Mean of values of foliar disease index, vascular disease index and vascular disease rate.

Varieties	Foliar disease index (FDI)			Vascular disease index (VDI)			Vascular disease rate (%) (VDR)		
	Infected area (IA)	Non-infected area (NIA)	Average	Infected area (IA)	Non-infected area (NIA)	Average	Infected area (IA)	Non-infected area (NIA)	Average
1.GW-Teks	0.55	0.25	0.40^{e}	0.76	0.65	0.71^{de}	43.51	40.63	42.07^{cd}
2.GW-Golda	0.64	0.44	0.54^{d}	0.78	0.59	0.69^{de}	43.70	37.07	40.38^{cd}
3.Carmen ©	0.54	0.40	0.47^{de}	0.68	0.59	0.65^{e}	36.77	35.85	36.31^{d}
4.Şahin 2000	0.91	0.62	0.77^{bc}	0.98	0.66	0.82^{cd}	50.16	37.55	43.85^{c}
5.DP-Deltaopal	0.81	0.52	0.67^{c}	0.97	0.63	0.80^{cd}	50.98	35.42	43.20^{c}
6.Dicle 2002	1.00	0.76	0.88^{b}	1.04	0.83	0.94^{bc}	54.67	45.59	50.13^{ab}
7.Maraş 92	1.16	0.85	1.01^{a}	1.24	0.93	1.08^{a}	59.84	48.36	54.10^{a}
8.Stv. 453	1.02	0.70	0.86^{b}	1.19	0.79	0.99^{ab}	58.73	42.57	50.65^{ab}
9.Sayar 314 ©	1.21	0.95	1.08^{a}	1.24	0.86	1.05^{ab}	59.22	45.40	52.31^{a}
10.Nazilli 342	0.85	0.62	0.74^{c}	0.96	0.66	0.81^{cd}	51.76	38.95	45.35^{bc}
Mean	0.87^{a}	0.61^{b}		0.98^{a}	0.72^{b}		50.94^{a}	40.74^{b}	
CV (%)=25.67				CV (%)=27.05			CV (%)=21.29		
$LSD_{(0.05)}$				$LSD_{(0.05)}$			$LSD_{(0.05)}$		
Area: 0.07^{**}				Area: 0.05^{**}			Area: 1.89^{**}		
Variety: 0.10^{**}				Variety: 0.13^{**}			Variety: 5.53^{**}		

The differences among varieties, area and year were significant for vascular disease index (VDI). VDI was 0.98 in infected area and 0.72 in non-infected area. Varieties for this trait ranged from 0.65 for Carmen to 1.08 for Maraş 92. Carmen, GW-Golda and GW-Teks varieties were found tolerant to disease respectively and shared same statistically group, in contrast Maraş 92, Sayar 314 and Stoneville 453 were found as most sensitive varieties. Year×area and year×variety interactions were significant, the highest VDI (1.27) was obtained from infected area in 2005; the lowest VDI (0.51) was obtained from non-infected area in 2006. Year×variety interaction showed that the highest vascular disease index (1.53) was obtained from Stoneville 453 cotton variety in 2005, while the lowest vascular disease index (0.34) was obtained from Carmen variety in 2006. In terms of this trait, area×variety and year×area×variety interaction was non significant (Table 3).

Varieties, area, year, and also year×area, year×variety and year×area×variety interactions for vascular disease rate (VDR) were significant, but area×variety interaction was non-significant. Varieties for VDR ranged from 36.31% for Carmen to 54.10% for Maraş 92. Carmen, GW-Golda and GW-Teks varieties had the lower value than the other varieties. Vascular disease rate was found 50.94% in infected area and 40.74% in non-infected area. Highly significant differences were observed between years, the lowest vascular disease rate was obtained from third year of experiment. Year×area interaction was statistically significant and the lowest VDR (33.16%) was obtained from non-infected area in 2004, while the highest value (58.26%) was obtained from infected area in 2005.

Significant differences were obtained for first picking percentage, year, area, variety and year×variety interactions were significant at $P<0.01$ probability level, and year×area interaction was significant at $P<0.05$ probability level (Table 3). Varieties for first picking percentage ranged from 61.02% to 88.92%. Among the genotypes Dicle 2002 and Şahin 2000 had the higher value than the other varieties; the results also indicated that these varieties had the different genotypic performance for this trait. Average first picking percentage was observed as 83.37% in infected area and 76.69% in non-infected area. In infected area it was obtained approximately 10% higher first picking percentage (Table 5). Year×area interaction was significant; the highest first picking percentage was obtained from infected area in 2005, while the lowest value was obtained from non-infected area in 2004.

Table 5. Mean of values of first picking percentage, ginnning percentage and seed cotton yield.

Varieties	First Picking Percentage (%) (FPP)			Ginning Percentage (%) (GP)			Seed Cotton Yield (kg ha^{-1}) (SCY)		
	Infected area (IA)	Non-infected area (NIA)	Average	Infected area (IA)	Non-infected area (NIA)	Average	Infected area (IA)	Non-infected area (NIA)	Average
1.GW-Teks	78.55	72.77	75.66^{e}	42.63	42.13	42.37^{ab}	3769.2	3852.2	3810.7^{cd}
2.GW-Golda	84.24	78.29	81.27^{bc}	43.89	42.87	43.38^{a}	3768.3	4111.4	3939.9^{bc}
3.Carmen ©	67.26	54.78	61.02^{f}	42.70	41.56	42.13^{ab}	3795.3	3537.0	3666.2^{d}
4.Şahin 2000	90.49	85.83	88.16^{a}	39.80	39.59	39.70^{c}	3764.3	4119.1	3941.7^{bc}
5.DP-Deltaopal	80.97	74.73	77.85^{de}	41.08	40.91	40.99^{bc}	4187.2	4313.8	4250.5^{a}
6.Dicle 2002	92.05	85.80	88.92^{a}	39.89	39.66	39.77^{c}	3715.0	4431.4	4073.2^{ab}
7.Maraş 92	85.99	81.48	83.73^{b}	43.22	41.23	42.22^{ab}	3807.1	4463.0	4135.1^{ab}
8.Stv. 453	84.60	73.50	79.05^{cd}	41.20	42.15	41.68^{b}	3906.0	4423.9	4165.0^{ab}
9.Sayar 314 ©	83.05	79.95	81.50^{bc}	42.15	41.41	41.78^{b}	3742.1	4185.2	3963.7^{bc}
10.Nazilli 342	86.70	79.82	83.26^{b}	41.78	42.09	41.94^{ab}	3467.5	3720.4	3594.0^{d}
Mean	83.37^{a}	76.69^{b}		41.83	41.36		3792.2^{b}	4115.8^{a}	
CV (%)=6.77				CV (%)=5.88			CV (%)=9.61		
Area: 2.59**				Area: ns			Area: 29.13*		
Variety: 3.07**				Variety: 1.39**			Variety: 21.61**		

Varieties for ginning percentage ranged from 39.70% for Şahin 2000 to 43.38% for GW-Golda, with the differences among varieties being significant. Year, area, year×area, year×variety, area×variety and year×area×variety intarections were non-significant for this trait (Table 3).

For seed cotton yield year, area, year×area, variety, year×variety and area×variety interactions were significant. Varieties for seed cotton yield were ranged from 3594.00 kg ha^{-1} for Nazilli 342 to 4250.50 kg ha^{-1} for DP-Deltaopal (Table 5). Among the genotypes maximum seed cotton yield was obtained from DP-Deltaopal, Stoneville 453, Maraş 92 and Dicle 2002 varieties respectively and these cotton varieties shared same statistically group, while the lowest seed cotton yield was obtained from Nazilli 342 and Carmen varieties. This study indicated that some sensitive cotton varieties had higher seed cotton yield. Area differences were significantly different. The average seed cotton yield obtained from infected area was significantly lower than the yield obtained from non-infected area. Average seed cotton yield was determined as 3792.20 kg ha^{-1} in infected area and 4115.80 kg ha^{-1} in non-infected area. Year×area interaction was significant and the lowest seed cotton yield was obtained from infected area in 2006, while the highest seed cotton yield was obtained from non-infected area in 2004. Area×variety interaction showed that the highest seed cotton yield was obtained from Maraş 92 in non-infected area, while the lowest seed cotton yield was obtained from DP-Deltaopal variety in infected area.

The differences among varieties with respect to fiber yield was significant at ($P<0.01$) probability level. This trait was ranged from 1505.5 to 1745.3 kg ha^{-1}. The highest fiber yield were obtained from DP-Deltaopal, Stoneville 453, Maraş 92 and GW-Golda varieties respectively, and this varieties shared same statistically group. The lowest fiber yield was obtained from Nazilli 342, Carmen and Şahin 2000. Area differences were significant, fiber yield in infected area was 1585.7 kg ha^{-1} and non-infected area was 1700.2 kg ha^{-1}; it was obtained about 7.22% more fiber yield in non-infected area compared to infected area. Year, year×area, year×variety and area×variety interaction was also significant, but year×area×variety interaction was non significant for this trait. The highest fiber yield was obtained from non-infected area in 2004; the lowest fiber yield was obtained from infected area in 2006.

Year, area, variety was significant at ($P<0.01$) and year×variety interaction was significant at ($P<0.05$) for fiber length, but year×area, area×variety and year×area×variety interactions were non-significant for this trait. For fiber length varieties were ranged from 27.64 mm for Dicle 2002 to 29.41 mm to GW-Teks, area differences was also significant and 28.73 mm fiber length was obtained in non infected area, while 28.11 mm fiber length was obtained in infected area (Table 6).

Table 6. Mean of values of fiber yield, fiber length and fiber fineness.

Varieties	Fiber Yield (kg ha^{-1})			Fiber Length (mm)			Fiber Fineness (micronaire)		
	Infected area (IA)	Non-infected area (NIA)	Average	Infected area (IA)	Non-infected area (NIA)	Average	Infected area (IA)	Non-infected area (NIA)	Average
1.GW-Teks	1600.5	1619.1	1609.8^{c-e}	29.11	29.71	29.41^{a}	4.26	3.97	4.11^{de}
2.GW-Golda	1657.5	1761.7	1709.6^{a-e}	28.13	28.78	28.45^{bc}	4.51	4.10	4.31^{bcd}
3.Carmen ©	1625.8	1470.1	1548.0^{de}	28.03	28.57	28.30^{c}	4.30	4.02	4.16^{cde}
4.Şahin 2000	1499.7	1629.0	1564.4^{de}	28.09	28.58	28.33^{bc}	4.17	3.76	3.96^{e}
5.DP-Deltaopal	1722.4	1768.1	1745.3^{a}	28.43	28.87	28.65^{bc}	4.59	4.18	4.38^{abc}
6.Dicle 2002	1480.5	1754.6	1617.6^{b-e}	27.33	27.95	27.64^{d}	4.26	4.19	4.23^{bcd}
7.Maraş 92	1635.0	1839.0	1737.0^{ab}	27.39	28.12	27.75^{d}	4.77	4.40	4.59^{a}
8.Stv. 453	1611.4	1867.2	1739.3^{a}	28.26	29.28	28.77^{b}	4.41	4.44	4.43^{ab}
9.Sayar 314 ©	1576.1	1729.3	1652.7^{a-d}	28.42	28.61	28.51^{bc}	4.43	4.18	4.31^{bcd}
10.Nazilli 342	1447.6	1563.4	1505.5^{e}	28.35	28.84	28.60^{bc}	4.25	3.90	4.07^{de}
Mean	1585.7^{b}	1700.2^{a}		28.11^{b}	28.73^{a}		4.40^{a}	4.11^{b}	
CV (%)=10.87				CV (%)=2.84			CV (%)=9.64		
Area: 13.83*				Area: 0.15**			Area: 0.16**		
Variety: 10.15**				Variety: 0.45**			Variety: 0.21**		

The differences of variety, area and year was significant at ($P<0.01$) for fiber fineness, but year×area, year×variety, area×variety and year×area×variety interaction was non significant for this trait. For fiber fineness varieties were ranged from 3.96 micronaire for Şahin 2000 to 4.59 micronaire for Maraş 92. Area differences were also significant, average fiber fineness of cotton varieties in infected area was 4.40 mic, and non infected area was 4.11 mic. (Table 6).

The differences among varieties with respect to fibre strength was significant at ($P<0.01$) probability level. This trait ranged between 28.35 g tex^{-1} to 36.53 g tex^{-1}. The strongest fiber were obtained from GW-Teks (36.53 g tex^{-1}), GW-Golda (32.95 g tex^{-1}), DP-Deltaopal (32.57 g tex^{-1}) and Carmen (32.05 g tex^{-1}) respectively and the weakest fibre were obtained from Şahin 2000 (28.35 g tex^{-1}). Area differences were also significant, the average fiber strength in infected area was 30.47 g tex^{-1}, but in non-infected area was 31.50 g tex^{-1}, non infected area exhibited higher fiber strength (Table 7). Year differences was found significant, highest fiber strength was obtained from 2006. For fiber strength year×variety interaction was significant, but year×area, area×variety and year×area×variety interaction was not significant.

Area, variety and year×variety interaction was significant for fiber elongation, but year, year×area, area×variety and year×area×variety interactions were not significant for this trait. For fiber elongation varieties were changed from 5.24 for Nazilli 342 to 7.26 for Şahin 2000. Elongation value of non infected area was higher than infected area (Table 7).

The differences among varieties with respect to fibre uniformity ratio were significant and this trait changed from 84.13% to 86.38%. The highest uniformity ratio was recorded for GW-Teks, but the lowest uniformity ratio was recorded for Dicle 2002. Area differences were also significant, the average fiber uniformity in infected area was 84.78%, in non-infected area was 85.13%, non infected area exhibited higher fiber uniformity than infected area (Table 7). For this trait year also significant and the highest values were obtained from first year of experiment.

Table 7. Mean of values of fiber strength, fiber elongation and uniformity.

Varieties	Fiber Strength (g tex^{-1})			Elongation (%)			Uniformity (%)		
	Infected area (IA)	Non-infected area (NIA)	Average	Infected area (IA)	Non-infected area (NIA)	Average	Infected area (IA)	Non-infected area (NIA)	Average
1.GW-Teks	36.10	36.96	36.53^{a}	6.11	6.00	6.05^{bc}	85.95	86.81	86.38^{a}
2.GW-Golda	32.05	33.84	32.95^{b}	5.99	6.15	6.07^{bc}	85.60	85.77	85.69^{b}
3.Carmen (C)	31.78	32.31	32.05^{b}	5.59	5.51	5.55^{e}	85.45	84.88	85.17^{bcd}
4.Şahin 2000	27.89	28.81	28.35^{d}	7.00	7.52	7.26^{a}	84.22	84.09	84.15^{e}
5.DP-Deltaopal	32.46	32.69	32.57^{b}	6.05	6.02	6.03^{bc}	85.23	85.37	85.30^{bc}
6.Dicle 2002	28.04	29.69	28.86^{cd}	6.15	6.25	6.20^{b}	83.95	84.30	84.13^{e}
7.Maraş 92	29.22	30.09	29.65^{c}	5.82	5.96	5.89^{cd}	84.16	85.05	84.61^{de}
8.Stv. 453	28.52	30.62	29.57^{c}	6.00	6.18	6.09^{b}	84.43	85.73	85.08^{cd}
9.Sayar 314 (C)	29.60	29.85	29.72^{c}	5.65	5.80	5.73^{de}	84.04	84.64	84.34^{e}
10.Nazilli 342	29.10	30.13	29.61^{c}	5.22	5.26	5.24^{f}	84.78	84.61	84.70^{de}
Mean	30.47^{b}	31.50^{a}		5.96^{b}	6.07^{a}		84.78^{b}	85.13^{a}	
CV (%)=5.42				CV (%)=5.49			CV (%)=1.21		
Area: 0.33**				Area: 0.11*			Area: 0.29*		
Variety: 0.94**				Variety: 0.17**			Variety: 0.57**		

For fiber reflectance year, area, year×area, variety and year×variety interaction was found significant, but area×variety and year×area×variety interaction was not significant. Varieties for fiber reflectance changed from 73.94 to 76.89%, and DP-Deltaopal, Carmen and GW-Teks varieties provided the highest value respectively and shared same statistically group (Table 8). Year differences were also significant and the higher reflectance was obtained from first year of the study.

In terms of yellowness (+b), year, area, year×area, variety and year×variety interaction was significant, varieties for this traits were changed from 7.34 for Carmen to 7.69 for GW-Golda and Maraş 92. Area differences were also significant and yellowness (+b) value was recorded as 7.37 for non-infected area and 7.62 for infected area (Table 8). Average yellowness value for infected area was slightly higher than non infected area. Also higher yellowness value was obtained from first year of the study.

Differences among varieties, year, area and year×variety interaction were significant at ($P<0.01$) probability level for spinning consistency index (SCI). Varieties for this trait were ranged from 133.91 to 171.70. GW-Teks variety had the highest value for SCI. Area differences were also significant, in infected area SCI value was recorded as 140.84 and in non infected area was recorded as 149.62 (Table 8).

Correlation coefficients among the investigated characteristics are given in Table 9. It can be seen that vascular disease rate (VDR) was positive and significantly correlated with first picking percentage and yellowness; negative and significantly correlated with seed cotton yield, fiber length, spinning consistency index and reflectance. Vascular disease index (VDI) was positive and significantly correlated with first picking percentage, yellowness and vascular disease index; but negative and significantly correlated with fiber length, spinning consistency index and reflectance. Foliar disease index (FDI) was positive and significantly correlated with first picking percentage, fiber fineness, yellowness, vascular disease rate and vascular disease index. Foliar disease index was significant and negatively correlated with fiber length, fiber strength, fiber uniformity, spinning consistency index and reflectance.

Table 8. Mean of values of reflectance, yellowness and spinning consistency index.

Varieties	Reflectance (%)			Yellowness (+b)			Spinning Consistency Index (SCI)		
	Infected area (IA)	Non-infected area (NIA)	Average	Infected area (IA)	Non-infected area (NIA)	Average	Infected area (IA)	Non-infected area (NIA)	Average
1.GW-Teks	76.56	76.68	76.62^{a}	7.61	7.31	7.46^{b-e}	166.50	176.91	171.70^{a}
2.GW-Golda	75.26	76.36	75.81^{ab}	7.82	7.56	7.69^{a}	148.25	160.00	154.12^{b}
3.Carmen (C)	76.37	77.27	76.82^{a}	7.49	7.19	7.34^{e}	148.91	152.16	150.54^{b}
4.Şahin 2000	76.08	77.01	76.55^{ab}	7.72	7.30	7.51^{bcd}	133.25	140.41	136.83^{cd}
5.DP-Deltaopal	76.51	77.27	76.89^{a}	7.55	7.16	7.36^{de}	148.08	154.33	151.20^{b}
6.Dicle 2002	75.54	76.40	75.97^{ab}	7.45	7.34	7.40^{cde}	129.50	138.33	133.91^{d}
7.Maraş 92	73.48	75.28	74.38^{c}	7.76	7.62	7.69^{a}	128.25	141.00	134.62^{d}
8.Stv. 453	73.74	74.14	73.94^{c}	7.65	7.49	7.57^{ab}	132.58	146.58	139.58^{cd}
9.Sayar 314 (C)	74.59	74.24	74.42^{c}	7.67	7.42	7.55^{abc}	134.50	140.50	137.50^{cd}
10.Nazilli 342	75.37	75.63	75.50^{b}	7.50	7.29	7.39^{cde}	138.58	146.00	142.29^{c}
Mean	75.35^{b}	76.03^{a}		7.62^{a}	7.37^{b}		140.84^{b}	149.62^{a}	
CV (%)=2.40				CV (%)=3.83			CV (%)=7.53		
Area: 0.81^{*}				Area: 0.09^{**}			Area: 2.44^{**}		
Variety: 1.02^{**}				Variety: 0.15^{**}			Variety: 6.22^{**}		

Table 9. Correlations coefficient among the investigated characteristics.

VDR	VDI	FDI	
-0.1643*	-0.1307	-0.0905	SCY
0.2362**	0.2174**	0.3704**	FPP
0.1042	0.0902	0.1730*	FF
0.0779	0.0282	0.0424	GP
-0.1170	-0.1130	-0.0649	FY
-0.2463**	-0.2466**	-0.3889**	FL
-0.1371	-0.1419	-0.4470**	FS
0.8063	-0.0599	0.0015	ELG
-0.0765	-0.0626	-0.2692**	UNF
-0.1806*	-0.1704*	-0.4559**	SCI
-0.2910**	-0.2473**	-0.3041**	R (Rd)
0.2486**	0.2268**	0.2924**	Y (+b)
-	0.9582**	0.5994**	VDR
-	-	0.6415**	VDI

*, ** Significant at 0.05 and 0.01 level of probability, respectively.
SCY=Seed cotton yield, FPP=First Picking Percentage, FF=Fiber fineness, GP=Ginning percentage, FY=Fiber yield, FL=Fiber length, FS=Fiber strength, ELG=Elongation, UNF=Uniformity, SCI=Spinning consistency index, R=Reflectance (Rd), Y=Yellowness (+b), VDR=Vascular disease rate, VDI=Vascular disease index, FDI=Foliar desease index.

Discussion

The results of this study indicated that area differences were significant for foliar disease index, vascular disease index, vascular disease rate, first picking percentage, seed cotton yield, fiber yield, fiber length, fineness, strenght, elongation, uniformity, reflectance, yellowness and spinning consistency index except ginning percentage. The results of the non infected area showed that there were decreasing with regard to foliar disease index, vascular disease index, vascular disease rate, first picking percentage, micronaire and yellowness, while increasing with regard to seed cotton yield, fiber yield, fiber length, strength, elongation, uniformity, reflectance and spinning consistecy index.

With planting cotton varieties in non infected area there were 323.60 kg ha^{-1} increase for seed cotton yield and 114.50 kg ha^{-1} for fiber yield. Disease led to a decrease (7.86%) in seed cotton yield and 6.73% in fiber yield. Similar results were reported by Erdogan et al., 2006 who determined that yield reduction was 15.93%. Bejarano-Alcazar, 1997, explained about 70% of the variation in cotton yield loss due to *Verticillium wilt.* Pullman

and Devay, 1982, revealed that cotton lint reductions due to *Verticillium wilt* were small when foliar symptoms appeared after mid-August.

Bassett, 1974, explained that ratings based on visual estimates of foliar damage made in either August or September were most closely related to yield performance, accounting for 35 to 65% of the yield variation among the cottons in five of the six tests. Percentages of plants showing early foliar symptoms were less well correlated with yield, while postharvest vascular ratings showed virtually no yield correlation.

The results of this study indicated that resistance of cotton varieties to *Verticillium wilt* was highly depended on varieties, among the cotton varieties GW-Teks, GW-Golda and Carmen were tolerant; Maraş 92, Sayar 314 and Stoneville 453 were sensitive for FDI, VDI and VDR. Response of cotton varieties against to FDI, VDI and VDR were similar. The other varieties had moderate tolerance level. Highest seed cotton yield and fiber yield were obtained from Deltaopal, Stoneville 453 and Maraş 92, these results showed that some sensitive varieties had high yield. The reason of this situation may be related with diseases timing and it shows the importance of disease beginning date.

According to the results it was determined that with regards to foliar diseases index, vascular disease index and vascular disease rate, the most tolerant varieties were GW-Teks, Golda and Carmen while the most sensitive varieties were Maraş 92 and Sayar 314. Evaluating of three years results showed that *Verticillium dahliae* causes decreasing in seed cotton yield and lint yield, the period of disease is effective on varieties yield performance, in infected field one should prefer tolerant varieties and the most important result is if one apply crop rotations it will be possible to decreasing effect of *Verticillium dahliae* in cotton production area.

It was observed that *Verticillium wilt* had detrimental effect on cotton fiber technological properties, addition to seed cotton yield and fiber yield; fiber quality traits were decreased due to disease; fiber length, fiber strength, elongation, uniformity, reflectance and spinning consistency index were decreased in infected field, but fiber fineness, yellowness and first picking percentage were increased in infected field. Except ginning percentage all of the investigated characteristics effected from area differences. Non significant differences was observed between infected and non infected area and area×variety interactions, this findings showed that ginning percentage not affected from *Verticillium*, similar results were reported by El-Zik (1985) and Erdogan et al. (2006); but not consistent with Sagır and Basbag, 2002.

Correlation analysis confirmed these findings, significant and positive correlation was found between vascular disease rate (VDR) and first picking percentage and also yellowness; but negative and significant correlation was found between seed cotton yield, fiber length, spinning consistency index and reflectance. Vascular disease index (VDI) was positive and significantly correlated with first picking percentage, yellowness and vascular disease index; but negative and significantly correlated with fiber length, spinning consistency index and reflectance. Foliar disease index (FDI) was positive and significantly correlated with first picking percentage, fiber fineness, yellowness, vascular disease rate and vascular disease index. Foliar disease index was significant and negatively correlated with fiber length, fiber strength, fiber uniformity, spinning consistency index and reflectance.

Zhang et al., 2011 revealed that verticillium wilt (VW) significantly reduced cotton yield, lint percentage, 50% span length and micronaire, but not 2.5% span length and fiber strength, when healthy and diseased plants in 23 cultivars were compared. In another study reported by Aguado et al. 2010, elongation was the trait most correlated with seed cotton yield. Strength and micronaire were the traits most correlated with Verticilium Wilt (VW).

GW-Teks, Carmen and GW-Golda varieties had the lowest foliar disease index, vascular disease index and vascular disease rate and better fiber quality, indicating that these cotton varieties are potantially useful sources for germplasm in resistance breeding programs.

All the investigated traits were affected from year differences except ginning percentage and elongation, this findings reflected to climatical conditions differences during experiment.

The results of this study showed that non infected area causes decreasing in wilt diseases and diseases rate and with growing cotton varieties in that area it can be obtained higher yield, better guality cotton and lint. By this way it can be provided lint of the textile industry requirements.

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