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Evaluation of some cotton genotypes for resistance to *Verticillium dahliae Kleb*. under field conditions

Bazı pamuk hatlarının tarla koşullarında *Verticillium dahliae Kleb*. solgunluğuna duyarlılıklarının belirlenmesi

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A B S T R A C T

Verticillium wilt caused by the soil-borne pathogen is one of the most significant diseases affecting the yield of cotton and is almost incurable with chemical agents. For this reason, it will be inevitable to cultivate resistant varieties. In this direction, this study was carried out to determine the response of cotton varieties and inbred lines obtained from cotton breeding projects of the GAP International Agricultural Research and Training Center (GAPUTAEM) in Diyarbakır, Türkiye to Verticillium wilt disease. The trial was conducted in a randomized complete block design with four replications during the 2016 and 2017 cotton growing seasons. In the study, 12 advanced inbred lines (8, 20, 30, 34, 38, 57, 58, 63, 64, 8/4, 5/7, and 8/1) and 3 control varieties [Stoneville 468, Carmen (tolerant control), and Çukurova-1518 (sensitive-control)] were tested for the response to Verticillium wilt under naturally infected field conditions. Disease severity was determined in the leaf at 5-10% and 50-60% of the boll opening stages and in the stem section after harvest. Additionally, some yield parameters and fiber quality properties were investigated in the study. The results indicated that there were significant differences among genotypes for most of the investigated characteristics.It was determined that with regard to foliar disease index (FDI) as mentioned boll opening stages and disease index of stem cross-section (SDI) the most tolerant genotype was inbred line 38, while the most sensitive variety was Çukurova-1518. As a result of their low disease index value and high yield capacity, the inbred lines 30, 57, 38, and 20 were recommended.

INTRODUCTION

The cotton grown in hot climate conditions is a one-year plant whose effective root depth is generally accepted as 90 cm with not much soil selectivity but needs more water (Aydogdu et al. 2018). It is a significant agricultural crop that meets the crude material demands of many industry branches. The rise in the standard of living in developing societies leads to an increase in fashion brand awareness, and therefore the cotton and textile sectors are gaining importance day by day. Cotton is mostly produced and processed in developing countries, whereas the highest per capita consumption of cotton occurs in developed countries due to the significant resource of cellulose in natural fibers. Türkiye has desirable ecological farming conditions and cotton production practices that have lasted for centuries. With its direct and indirect employment effects, cotton is considered a source of income for a lot of people in Türkiye, and is grown intensively in the Southeastern Anatolia Region, the Aegean Region, Adana, and Antalya regions, especially with the determinant climatic factors. Among the biotic stresses, plant disease is a vital limiting factor that disrupts plant production. Over 40 diseases induced by nematodes bacteria, fungi, and viruses have been identified in cotton. In particular, fungi are responsible for approximately two-thirds of infectious plant diseases (Carris et al. 2012). *Verticillium dahliae* is the leading cause of Verticillium wilt and its resting body microsclerotia can survive for up to 14 years in the absence of a host or under adverse conditions (Short et al. 2015). Verticillium wilt is most important in temperate regions, occurs less frequently in the subtropics, and is rare in the tropical areas of the world (Inderbitzin and Subbarao 2014). In recent years, the disease has become increasingly serious due to climatic variation, long-term monoculture, and frequent introduction of new cotton varieties in different countries and regions in the world (Ranga et al. 2020). The control of disease is difficult due to its being a soil-borne pathogen and impractical and expensive soil sterilization practices (Bicici and Kurt 1998). In 1914, Verticillium wilt was first reported in Virginia and afterward spread to many cotton-growing areas worldwide. Enormous losses occur every year in many cotton-producing areas of the world, which restrict certain factors for cotton production. Contaminated plants usually exhibit symptoms of marginal necrosis or chlorosis in their leaves, discoloration of the stem vascular bundles, decreased photosynthesis, and increased respiration, which result in a significant reduction of the plant's biomass and a heavy loss of yield (Hampton et al. 1990). The disease can be controlled with the use of tolerant plants and traditional practices. Nevertheless, no genetic resources of resistance prevent contamination of the vascular system, and neither of the recent upland cotton cultivars is resistant to *V. dahliae.* Hence, determining the susceptibility of cotton cultivars and cultivar candidates bred in Türkiye and brought from abroad is essential. In Türkiye, Verticillium wilt was first detected by Iyriboz in Manisa Kırkağaç in 1941, but the *Verticillium dahliae* Kleb. was reported by Karaca et al. (1971). Then, the disease was reported to be spread in the Aegean and Mediterranean regions by Esentepe (1979). Verticillium wilt also causes a significant reduction in yield in the Southeastern Anatolia Region. The frequency of occurrence of Verticillium wilt disease was 16.27%, and the prevalence rate was 79.28% in some districts of the region (Siirt, Mardin, Batman, Diyarbakır, Adıyaman and Şanlıurfa). By conducting numerous trials in those regions, it has been observed that this disease's widespread rate was 86% (Sağır et al. 1991). Plants infected at early stages are severely stunted. At first glance, Verticillium wilt migrates from the root to the tissue, nestles in the xylem, and causes occlusion of the stem veins. Chlorosis, necrosis and vascular discoloration on leaves and stems are considered the first signs of disease, and then wilting appears. Pathogens prevent the transport of water and other mineral substances from the roots to the leaves and tissues. From the bottom leaves, this disease stimulates wilting, drying, a reduced photosynthesis rate, and reduced yield and quality of fiber parameters. Significantly, infected plants shed all their leaves and most of their young bolls. The need for improving significant strategies against cotton wilt has emerged. Thus, the use of resistant varieties derived from genetic resources has been considered the most practical and effective way of managing the disease (Baran et al. 2022).

Marani and Yaacobi (1976) observed that appropriate scanning for wilt resistance in Israel appears practical by examining foliar symptoms throughout the second part of the bloom period when the area is uniformly infected by the fungus under convenient temperatures. Bolek et al. (2005) determined that by using four *Verticillium dahliae* isolates (V44, V76, TS-2 and PH) in scanning four cotton cultivars (Acala 44, Pima S-7, M-315 and Acala Prema), Pima S-7 and Acala Prema executed the tolerance reactions, while Acala 44 was considered the most sensitive cultivar. This study revealed that the number of uninfected leaves and total shoot weight were considered the best signs of resistance. Erdogan et al. (2006), evaluated cultivars' tolerance to the disease and concluded that Carmen's yield and fiber properties made it a good choice in contaminated fields. As a consequence of the increased population, natural fibers and cotton are becoming more important and demandable. This experiment was conducted to determine the most tolerant inbred lines that were developed by GAPUTAEM's breeding programs as well as contribute to future cotton breeding programs.

MATERIALS AND METHODS

The trial was conducted in GAPUTAEM's experimentel field during the 2016-2017 years in Diyarbakır, Türkiye. In the study, 12 inbred lines (8, 20, 30, 34, 38, 57, 58, 63, 64, 8/4, 5/7 and 8/1) and three control varieties were planted in the infected field with Verticillium wilt. Stoneville-468 (tolerant), Carmen (tolerant) and Çukurova-1518 (susceptible) were tested as control varieties in the trial. The study was designed as a randomized complete block design with four replications. Each plot comprises four rows of 12 m in length, 70 cm interrow row spacing, and 15-20 cm above row spacing.

Soil characteristics of the experimental area

The experimental site was flat and devoid of organic substances, and had no salinity issues. Depending on the abundance of clay minerals, the soil profile was expanded and swollen during winter, and deep cracks were formed 80-90 cm from the top level of soil in summer (Avşar and Karademir 2022). Soil specimens received from the 0-30 cm soil stratum of the experimental area were analyzed in the GAPUTAEM soil analysis laboratory (Table 1).

Table 1. Soil properties of the research area

Texture	Clay-Loam (C-L)
EC (dS m^{-1})	1.27
pH	8.10
$CaC0_3$ (%)	11.46
P_2O_5 (kg ha^{-1})	3.21
K_2O (kg ha^{-1})	243
Organic Matter (%)	0.98
Bulk Density (g/cm^3)	1.19

Meteorological data for the experimental area

The average temperature, average maximum temperature, precipitation amount, and average relative humidity taken from the meteorological service in Diyarbakır are presented in Table 2. The maximum temperature values of June, July and August 2016 and 2017 were higher than long-term mean values, while the precipitation amounts of April 2017 and May, June and September 2016 were long-term mean values. The relative humidity of July, August, September and October in both years of the trials was below the mean values for long years. In Diyarbakır province, long-term climatic data indicated that there was 210 mm of total precipitation and a 21.56 ºC mean temperature. The highest average maximum temperature was 40.7 ºC in July 2017, and the highest average rainfall was 68.5 mm in April 2017. The disease severity index was measured using data on foliar and vascular symptoms. Leaf and stem sections of 50 consecutive plants were examined for disease in each plot.

Determination of foliar disease severity index in leaves

Wilt disease in the leaves, was evaluated when plants reached approximately 5-10% and 50-60% boll opening time, and to calculate the foliar disease severity index (FDI), a 0-4 scale discovered by Bejarano-Alcazar et al. (1995) is used (Table 3). FDI was measured with the index formula given below (Karman 1971).

$$FDI= \frac{(0)(a)+(1)(b)+(2)(c)+(3)(d)+(4)(e)}{N} \quad (1)$$

n= (a+b+c+d+e)

a,b,c,d,e: Number of plants included in each scale value

n: Total of the plants

0,1,2,3,4: Scale data

In the "0, 1, 2, 3, and 4" scale data of the leaf disease severity index, "a, b, c, d, and e" symbolized the number of plants included in each scale value, and "N" indicates the total number of plants. As the data goes towards 0, the leaf becomes more tolerant to the disease. However, when the trend goes

Table 2. Monthly climate data during the growth period of cotton in 2016-2017 and long-term averages in Diyarbakır*

Months	Avg. temp. (°C)			Avg. max.temp. (˚C)			Precipitation (mm)			Avg. relative humidity (%)		
	2016	2017	Long term avg.	2016	2017	Long term avg.	2016	2017	Long term avg.	2016	2017	Long term avg.
April	15.7	12.8	13.8	28.8	19.5	20.2	29	98.8	68.7	56.2	68.5	63
May	19.9	18.8	19.2	27.5	26.3	26.5	41.4	30.6	42.8	51.9	57.6	56
June	26.8	26.9	26.3	34.7	35	33.5	18.4	2.6	8	32	30	31
July	31.6	32.3	31.1	39.2	40.7	38.3	0	0	0.7	23	19.4	27
August	31.9	31.1	30.4	40.5	39.9	38.2	0	0	0.4	22.7	22.8	28
September	24.2	26.8	24.9	31.9	36.4	33.2	5.2	0	3.9	29.9	22.3	32
October	18.8	17.2	17.3	26.7	24.8	25.3	13.6	22	31.7	36.9	39.2	48
November	8.2	10	9.5	16.4	16.3	16.2	52	21.2	53.8	54	67.5	55

*Source: Turkish State Meteorological Service, Diyarbakırasu toward 4, it means the sensitivity to disease is increasing (Karman 1971).

Table 3. Scale values of wilt disease in leaves

Disease Scale Value (0-4)	Disease Symptoms
0	No symptoms on the plant (plants are healthy)
1	On the leaves of the plant, there are symptoms at the beginning stage, very little yellowing and unclear symptoms (1-33%)
2	Yellowing of the leaves, interveinal necrosis and leaf fall (34-66%)
3	Local necrosis between the leaf veins of the plant, defoliation and shriveling of all parts of the plant (i.e. going towards death) (67-97%)
4	Dying and death plant (98-100%)

Determination of severity disease index in cross stem section

Cotton plants were cut at a height of 5 cm from the soil level at an angle of 45 degrees from the root collar. By examining the discoloration of the wood tissue of the cut plants, a 0-3 scale that was discovered by Buchenauer and Erwin (1976) for stem cross-sectioning was used (Table 4).

Disease index of stem cross-section (SDI) was measured with index formula given below;

$$SDI= \frac{(0)(a)+(1)(b)+(2)(c)+(3)(d)}{N} \quad (2)$$

n= (a+b+c+d)

a,b,c,d: Sum of plants included in each scale value

n: Sum of the plants

0,1,2,3: Scale data

The measured grades "0, 1, 2, 3" represent the scale data in accordance with the stem section disease severity index; "a, b, c, d" represent the number of plants comprised in each scale value; and "N" stands for the total number of plants processed. As the stem section disease severity index data goes toward 0, the stem section indicates that plants are getting more resistant to the disease. Nevertheless, if the data is directed towards 3, that means plants are getting more sensitive to the disease (Karman 1971). Statistical analyses were conducted using JMP 5.0.1 statistical software with the LSD (0.05) test.

Table 4. Scale values of wilt disease on stem section

Disease Scale Value (0-3)	Disease Symptoms
0	No browning (discoloration) in wood (xylem) tissue
1	The browning and black spots (discoloration) 1-33% in the wood (xylem) tissue of the plant
2	The 34-67% of browning and black spots (discoloration) in the wood (xylem) tissue of the plant
3	Browning and darkening 68-100% (discoloration) in the plant wood (xylem) tissue

RESULTS AND DISCUSSION

Based on variance analysis outcomes of cotton genotypes, there were statistically considerable differences at the P<0.01 level between genotypes with regard to FDI at the boll opening stage of 5-10%, 50-60%, and SDI (Table 5). Two different defense systems, called resistance and tolerance, ensure a host's survival against infectious diseases. Resistance is based on the ability of the host to kill pathogens while tolerance is defined as a plant's ability to sustain yield in the presence of disease (Newton 2016). The mean values of observed traits for years, genotypes and year*genotypes interactions were presented in Table 6. Values of disease severity based on FDI at the boll opening stage of 5-10% were observed to be prominent between cotton genotypes (P≤0.01) (Table 6). Additionally, FDI at the boll opening stage of 5-10% grouped into "e" (0.61-0.65) were the most tolerant genotypes to wilt disease (*Verticillium dahlia* Kleb.). In this study regarding FDI at the boll opening stage of 5-10%, inbred lines 20, 38, 57 and 58 had lower values in comparison with Carmen, although Carmen is presented as a tolerant variety to Verticillium wilt globally (Stathakos et al. 2006). Compared to other genotypes, Çukurova-1518 was the most susceptible variety with a 0.98 value. These results were in parallel with Erdoğan et al. (2015), who reported that the highest disease intensity value was observed in Çukurova 1518 (2.53) in accordance with the severity of the disease. As seen in Table 6, data analysis indicated that the differences among years in FDI at the boll opening stage of 5-10% were statistically significant. As years compared, lower FDI at the boll opening stage of 5-10% was obtained in 2016 with a 0.68 value, while a higher value was observed in 2017 with a value of 0.76. A similar study carried out in Diyarbakır stated that Carmen, Golda, and Teks were tolerant while Stonville 453, Sayar 314 and Maraş 92 cultivars were susceptible varieties based on the disease severity in leaf (Karademir et al. 2012). Genotypes and year*genotypes interactions for FDI at 50-60% boll opening stage were significant, while the differences between years were insignificant. Genotypes for FDI at the boll opening stage of 50-60%, ranged from 0.71 for an inbred line called 58 to the value of 1.15 for the Çukurova-1518 variety. According to Baran (2022), the leaf-disease severity varied between 0.12-3.09 at 50-60% at the boll opening period, whilst stem cross-section values ranged between 0.36-2.30 and a positive correlation was found between the indices. Our results contribute to the outcomes of Erdoğan (2009) and Korkmaz (2005) who recorded that cotton genotypes had different susceptibilities to Verticillium wilt disease, even though Stoneville-468 is considered one of the most tolerant cotton varieties in worldwide. According to this study, taking into account FDI at the boll opening stage of 5-10%, inbred lines 8, 20, 38, 58 and Carmen variety were depicted with lower values compared to Stoneville-468 which is known to be to Verticillium pathogens (Sağır et al. 2021).

Table 5. Variance analysis of mean squares

Variance Sources	DF	FDI at boll opening stage of 5–10%	FDI at boll opening stage of 50–60%	SDI
0	1	52.2796**	0.9588	3514.715**
1	14	9.6375**	4.1137**	21.0122**
2	14	2.354**	1.8893*	9.0306**
3	84	0.007958	0.023901	0.016347
	119	2.2211592	4.207997	13.86106

** P<0.01, * P<0.05, DF: Degrees of Freedom, FDI: Foliar Disease Index, SDI: Severity Disease Index of stem cross-section

Table 6. Mean values of FDI at boll opening stage of 5–10%, FDI at boll opening stage of 50–60%, and SDI

Genotypes	FDI at boll opening stage of 5-10%			FDI at boll opening stage of 50-60%			SDI		
	2016	2017	Mean	2016	2017	Mean	2016	2017	Mean
8	0.78 cd	0.72 c-e	0.75 b-d	0.75 ef	0.82 d-f	0.79 cd	1.4 f-h	1.72 cd	1.56 de
20	0.53 g	0.7 c-f	0.61 e	0.7 fg	0.82 d-f	0.76 cd	1..25 h-k	1.75 b-d	1.5 ef
30	0.63 e-g	0.72 c-e	0.67 c-e	0.98 b-d	0.82 d-f	0.90 bc	1.6 d-e	1.72 c-d	1.66 cd
Stoneville-468	0.73 c-e	0.75 c-e	0.74 b-d	0.73 e-g	0.9 c-f	0.81 cd	1.1 k-m	1.87 a-c	1.49 ef
34	0.73 c-e	0.8 c	0.76 b	0.9 c-f	0.89 c-f	0.89 bc	0.95 m	1.52 e-f	1.24 ı
38	0.58 fg	0.72 c-e	0.65 e	0.75 ef	0.77 d-f	0.76 cd	0.95 m	1.75 b-d	1.35 g-ı
57	0.5 g	0.77 cd	0.64 e	0.93 c-e	0.87 d-f	0.9 bc	1.65 de	1.9 a-c	1.78 bc
58	0.58 fg	0.67 d-f	0.62 e	0.53 g	0.9 c-f	0.71 d	1.35 f-ı	1.41 f-h	1.38 f-h
CARMEN	0.63e-g	0.71 c-e	0.67 de	0.75 ef	0.81 d-f	0.78 cd	1 lm	1.61 de	1.31 hı
63	0.75 c-e	0.77 cd	0.76 bc	0.85 d-f	0.87 d-f	0.86 cd	1.2 l-k	1.85 a-c	1.53 e
64	0.8 c	0.82 c	0.81 b	0.85 d-f	0.9 c-f	0.88 bc	0.95 m	1.75 b-d	1.35 g-ı
8/4	0.53 g	0.77 cd	0.65 e	0.75 ef	0.92 c-e	0.84 cd	1.75 b-d	1.92 ab	1.84 ab
Çukurova-1518	0.95 ab	1.2 a	0.98 a	1.2 a	1.1 a-c	1.15 a	1.9 a-c	2 a	1.95 a
5/7	0.8 c	0.75 c-e	0.78 b	0.88 d-f	0.82 d-f	0.85 cd	1.15 j-l	1.72 cd	1.44 e-g
8/1	0.83 bc	0.82 c	0.82 b	1.15 ab	0.9 c-f	1.03 ab	1.3 g-j	1.47 e-g	1.39 f-h
Mean	0.68 B	0.76 A		0.84	0.87		1.30 B	1.73 A	
CV(%)		12.27			17.64			7.94	
LSD $_{(0.05)}$									
Year		0.026**			N.S.			0.017 **	
Genotypes		0.08**			0.15 **			0.12 **	
Year*Genotypes		0.12**			0.21 **			0.17 **	

*and** significant at the 0.05 and 0.01 probability level respectively, N.S: Non Significant, CV: Coefficient of Variation

Table 7. Mean values of seed cotton yield, fiber yield and ginning percentage (%)

Genotypes	Seed cotton yield (kg ha^{-1})			Fiber Yield (kg ha^{-1})			Ginning Percentage (%)		
	2016	2017	Mean	2016	2017	Mean	2016	2017	Mean
8	4384 bc	1590 mn	2987 d-f	1869a-d	674 no	1271 e-f	42.6a-f	42.4 c-g	42.5 b-d
20	4310 bc	2229 kl	3270 b-e	1875 a-d	932 lm	1403 b-e	43.5 ab	41.8 f-ı	42.6 a-c
30	4880 a	2295 kl	3588 ab	2050 a	996 l	1523 ab	42 e-ı	43.4 a-c	42.7 ab
Stoneville-468	3823 de	2479 jk	3151 de	1656 e-g	1019 l	1341 d-f	43.5 ab	41.1 h-j	42.3 b-e
34	4114 cd	2461 jk	3288 b-d	1712 d-f	1073 kl	1392 b-e	41.6 f-ı	43.6 a	42.6 a-c
38	4690 ab	2339 k	3515 a-c	1952 a-c	1006 l	1478 b-c	41.6 f-ı	43 a-e	42.3 b-e
57	4414 a-c	2636 l-k	3525 a-c	1787 b-e	1081 kl	1434 b-d	40.5 j	41 ıj	40.7 f
58	3580 ef	2375 k	2978 d-f	1522 f-h	1024 l	1273 ef	42.5 b-g	43.1 a-d	42.8 ab
CARMEN	3484 e-g	1861 lm	2673 gf	1493 g-ı	763 mn	1129 gh	42.9 a-e	41 ıj	41.9 c-e
63	3750 d-f	1427 mn	2589 g	1541 f-h	605 no	1073 h	41.1 h-j	42.4 c-g	41.7 e
64	3600 ef	2288 kl	2944 ef	1496 g-h	963 l	1230 f-g	41.6 g-ı	42.1 d-h	41.8 de
8/4	4120 cd	2345 k	3233 c-e	1772 c-e	973 l	1372 c-e	43 a-e	41.5 g-j	42.2 b-e
Çukurova-1518	2874 h-j	1285 n	2080 h	1251 j-k	554 o	902 ı	43.5 ab	43.1 a-d	43.3 a
5/7	4640 ab	3018 g-ı	3829 a	1972 ab	1283 j	1627 a	42.5 b-g	42.5 b-g	42.5 b-d
8/1	3320 f-h	3102 g-ı	3211 c-e	1378 hj	1315 ıj	1347 d-f	41.5 g-j	42.4 c-g	41.9 c-e
Mean	3998 A	2248 B		1869 A	951 B		42.6	42.2	
CV(%)		10.71			10.2			1.7	
LSD (0.05)									
Year		12.41 **			42.79 **			N.S.	
Genotypes		33.12 **			134.02 **			0.72 **	
Year*Genotypes		46.86 **			189.54 **			1.01 **	

As indicated in Table 6, the differences among years, genotypes, and year*genotypes interactions were significant with regard to SDI value. When years were compared in terms of SDI, the value of 2017 (1.73) was higher than the value of 2016 (1.30). Çukurova 1518 variety (1.95) and 8/4 (1.84) inbred lines were detected as the most susceptible genotypes, while inbred line 34 with 1.24 SDI value was reported as the most tolerant genotype. These results were parallel with the study conducted by Erdoğan et al. (2015), who indicated the sensitivity of 13 cotton varieties improved by breeding against Verticillium wilt. It was reported that the minimum disease severity was noticed in Carmen, and the maximum disease severity value was defined in Çukurova 1518. Similarly, it was informed that the differences among cotton varieties were statistically significant with regard to the SDI values (Göre et al. 2017, Yaşar 2022). Even though Carmen is considered one of the most tolerant cotton varieties worldwide (Wheeler and Woodward 2016), in this study regarding SDI, inbred line 34 was shown lower value compared to the Carmen variety.

As seen from Table 7, there were statistically important differences between genotypes for seed cotton yield. The mean seed cotton yield values ranged from 2080 kg ha-1 (Çukurova - 1518) to 3829 kg ha-1 (5/7 inbred lines). The maximum value was obtained from the number inbred line 30, with a 4880 kg ha-1 and 4690 kg ha-1 value from number 38 in 2006, respectively. The data stated that some vulnerable genotypes had high yield values. The reason for this situation might be linked to the late onset of the disease. Higher seed cotton yield (3998 kg ha-1) was attained in the trial's first year (2016). It was estimated that the differences detected between the years of the experiment may be due to climatic or cultural alterations. As seen in Table 7, data analysis indicated that differences between years, genotypes and year*genotype interactions for fiber cotton yield were significant. Since the Çukurova-1518 variety is considered susceptible to Verticillium disease, high values were attained from FDI (5-10% and 50-60% boll opening stage) and SDI values, and also low yield values were seen in this variety. Lower cotton fiber yield was obtained in the trial's second year (2017). In 2017, higher precipitation amounts compared to average precipitation in long years, resulting in a delay in the sowing date, led to a decreased yield. Significant differences were received in terms of the ginning percentage of genotypes and year*genotypes and variety interactions at p<0.01 probability level, while differences between years

Table 8. Mean values of 100 seed weight and first flowering date

Genotypes	100 Seed Weight (g)			First flowering date (day)		
	2016	2017	Mean	2016	2017	Mean
8	11.4 c-e	12 b	11.7 b c	69	70	69
20	10.2 h-ı	11 d-f	10.6 e f	69	69	69
30	11.6 b c	11.5 b-d	11.6 b c	69	69	69
Stoneville-468	10.2 h-ı	10.5 f-g	10.4 f	68	69	68
34	11.6 bc	12 b	11.8 b	68	68	68
38	11.3 c-e	11.5 b-d	11.4 c	69	69	69
57	13.3 a	12 b	12.7 a	69	69	69
58	10.9 e f	11 d-f	11 d	69	69	69
CARMEN	10.2 h-ı	11 d-f	10.6 e f	68	69	69
63	10.9 e-f	12 b	11.5 b c	69	70	69
64	11.4 c-e	11.5 b-d	11.5 b c	69	70	69
8/4	10.6 f g	11 d-f	10.8 d e	69	69	69
Çukurova-1518	10.8 f	10 h-ı	10.4 f	69	70	69
5/7	10.5 f g	11 d-f	10.8 d e	68	69	69
8/1	9.9 ı	11 d-f	10.5 e f	68	69	68
Mean	11,02	11,27		68,5	69,1	
CV(%)		3,23			1,64	
LSD (0.05)						
Year		N.S.				
Genotypes		0.35 **				
Year*Genotypes		0.49 **				

Table 9. Mean values of fiber fineness, fiber length, fiber strength, fiber uniformity index, short fiber index and spinning consistency index

Genotypes	Fineness (mic)	Fiber Length (mm)	Fiber Strength (g/tex)	Fiber Uniformity Index (%)	Short Fiber Index (%)	Spinning Consistency Index (SCI)
8	3.42 c-e	30.2	32.6	84.32	7.26	150.5 b-d
20	3.47 cd	29.2	28.3	84.16	7.87	135.5 e
30	3.22 ef	29.2	32.4	84.7	7.38	159.5 ab
Stoneville-468	3.48 cd	29	28.9	84.42	7.72	149.5 b-d
34	3.75 ab	29.4	31.6	85.15	6.41	149.5 b-d
38	3.53 bc	29.5	32.6	85.76	6.43	159.5 ab
57	3.86 a	29.9	32.3	84.51	7.48	142 de
58	3.15 f	29.3	31.5	83.98	7.05	164.5 a
CARMEN	3.26 d-f	29.4	30.6	83.63	6.78	153.5 a-c
63	3.45 c-e	30	31.6	84.45	7.01	157 ab
64	3.22 ef	29.7	29.9	84.6	7.58	154 a-c
8/4	3.45 c-e	29.7	31.7	84.02	7.62	150.5 b-d
Çukurova-1518	3.28 d-f	29	29.8	83.66	6.78	151.5 b-d
5/7	3.61 bc	29.9	32.3	84.51	7.48	144.5 c-e
8/1	3.56 bc	29.6	30.5	83.86	7.45	137.5 e
Mean	3.45	29.5	30.98	84.51	7.19	150.6
CV(%)	4.63	2.1	7.3	1.21	10.15	5.19
LSD (0.05)	0.23**	N.S.	N.S.	N.S.	N.S.	11.13**

Table 10. Correlations coefficient among the investigated characteristics

FDI at boll opening stage of 50–60%	FDI at boll opening stage of 5–10%	0.5416	<.0001
SDI	FDI at boll opening stage of 5–10%	0.2966	0.0010
SDI	FDI at boll opening stage of 50–60%	0.2779	0.0021
First flowering date	FDI at boll opening stage of 5–10%	0.0670	0.4674
First flowering date	FDI at boll opening stage of 50–60%	0.0808	0.3803
First flowering date	SDI	0.2694	0.0029
Seed cotton yield	FDI at boll opening stage of 5–10%	-0.4012	<.0001
Seed cotton yield	FDI at boll opening stage of 50–60%	-0.1574	0.0860
Seed cotton yield	SDI	-0.5973	<.0001
Seed cotton yield	First flowering date	-0.2549	0.0050
Ginning Percentage	FDI at boll opening stage of 5–10%	0.0986	0.2839
Ginning Percentage	FDI atboll opening stage of 50–60%	-0.0719	0.4351
Ginning Percentage	SDI	-0.0368	0.6900
Ginning Percentage	First flowering date	0.0066	0.9429
Ginning Percentage	Seed cotton yield	-0.1160	0.2071
100 seed weight	FDI at boll opening stage of 5–10%	-0.2011	0.0276
100 seed weight	FDI at boll opening stage of 50–60%	-0.0520	0.5728
100 seed weight	SDI	0.1249	0.1740
100 seed weight	First flowering date	0.1550	0.0910
100 seed weight	Seed cotton yield	-0.0108	0.9068
100 seed weight	Ginning Percentage	-0.3022	0.0008

were found to be insignificant. Çukurova-1518 variety (43.3%) and 20 (42.6%), 30 (42.7%), 34 (42.6%) and 58 (42.8%) inbred lines had higher ginning percentages and were classified in the same group.

The mean values regarding 100 seed weight (g) and first flowering date (day) were given in Table 8. As indicated in the table, there were significant differences between genotypes in accordance with 100 cotton seed weights. Among the genotypes, the maximum 100 seed weight value was obtained from inbred line 57, while the lowest was obtained from the Stoneville-468 and Çukurova-1518 varieties. The differences between genotypes relating to the first flowering date were stated as insignificant.

Verticillium wilt may reduce the deposition and reorganization of cellulose molecules in cotton fiber. This could affect fiber yield and fiber properties, including micronaire, fiber maturity, short fiber content, and immature fiber content, as these are all related to cellulose deposition and reorganization in cotton fiber development (Ayele et al. 2020).

Fiber fineness (micronaire), fiber length (mm), fiber strength (g tex-1), fiber uniformity index, short fiber index, and spinning consistency index values were reported in Table 9. The genotypes were significantly different at P<0.01 level in terms of fiber fineness (micronaire), which related to maturity and spinning consistency index values. Genotypes with lower values for FDI at 5-10% boll opening stage had coarse fibers, as indicated in Table 6 and Table 8. This may be due to genotype-environment interactions as well as sowing dates and different cultural implementations. Regarding fiber fineness observed from Table 9, the values ranged from 3.15 mic. (inbred line 58) to 3.86 mic. (inbred line 57). Green and Culp (1990) reported that environmental variability, especially the differences in weather conditions, could influence the fiber quality parameters of cotton genotypes.

The differences among genotypes with respect to fiber length, fiber strength, fiber uniformity index, and short fiber index were indicated as insignificant (Table 9). Taking the spinning consistency index (SCI) into account, inbred line 58 had the highest value (164.5) and inbred line 20 had the lowest value (134.5).

Based on Table 10, FDI at the boll opening stage of 50-60% was positively and significantly correlated with FDI at the boll opening stage of 5-10%; positively correlated with SDI and first flowering date, and negatively correlated with seed cotton yield, ginning percentage and 100-seed weight. According to the research conducted by Baran and Temiz (2021), a positive correlation (r = 0.5616) was reported between the severity index for leaf disease at the boll opening period of 50–60% and the stem section. Likewise, Khaskheli (2013) informed us that positive and high correlation values (r = 0.966) between stem section and leaf disease severity index were found in all genotypes. In this research, SDI had a positive correlation with FDI at the boll opening stage of 5-10%, while the first flowering date had an important and negative correlation between SDI and seed cotton yield. The one hundred-seed weight of cotton was negatively correlated with seed cotton yield, ginning percentage, FDI at the boll opening stage of 5-10%, and FDI at the boll opening stage of 50-60%. On the other hand, a positive correlation was noticed between SDI and first flowering time (Table 10). In parallel to the study, similar research was performed to define the responses of several cotton varieties of different origins to wilt disease. According to outcomes from the trial carried out by Akışcan and Tok (2019), a highly positive and significant correlation (r= 0.972) between the disease severity indices data determined from the leaf and stem sections of the different cotton genotypes has been observed.

CONCLUSION

Verticillium dahliae Kleb. is an important fungal pathogen in cotton as in many plants. The disease limits the cotton yield at a great rate in Türkiye and worldwide, which does not have any economical chemical control way. In cotton breeding programs, developing resistant varieties is crucial to combat Verticillium wilt. The results showed that most of the properties examined in the study differed significantly among cotton genotypes (P<0.01). In light of these observations, 5/7, 30, 57, 38, and 20 inbred lines demonstrated tolerance in terms of three different periods of disease, and due to their high cotton yield performance, they could be recommended for infected areas. These genotypes can be used in breeding studies after testing in different locations, and the achieved results could be a guide for the forthcoming trials on the response against Verticillium wilt.

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Authors declare the contribution of the authors is equal.

Statement of Conflict of Interest
The authors have declared no conflict of interest.

ÖZET

Toprak kaynaklı patojenlerin neden olduğu Verticillium solgunluğu kimyasal mücadelesi olmayan ve pamuk verimini etkileyen en önemli hastalıklardan biridir. Bu nedenle dayanıklı çeşitlerin geliştirilmesi kaçınılmazdır. Bu çalışma ile GAP Uluslararası Tarımsal Araştırma ve Eğitim Merkezi Müdürlüğü (GAPUTAEM) tarafından ileri aşamalara getirilmiş verim ve kalitesi yüksek genotiplerin, Verticillium solgunluk hastalığına karşı toleransının belirlenmesi amaçlanmıştır. Bu amaçla, GAPUTAEM tarafından geliştirilmiş 12 adet ileri hat (8, 20, 30, 34, 38, 57, 58, 63, 64, 8/4, 5/7 ve 8/1) ve 3 adet kontrol çeşiti [Stoneville-468, Carmen (tolerant-kontrol), Çukurova-1518 (duyarlı-kontrol)] projede kullanılmak üzere seçilerek, hastalıkla doğal olarak bulaşık tarla koşullarında 2016 ve 2017 yıllarında test edilmiştir. Hastalık şiddeti yaprakta %5-10 ve %50-60 koza açma dönemlerinde ve hasattan sonra gövde kesitinde belirlenmiştir. Araştırmada bazı verim ve lif kalite parametreleri incelenmiştir. İncelenen birçok özellik arasında önemli düzeyde farklılıkların olduğu, belirtilen dönemlerde ve gövde kesiti hastalık okuma değerleri bakımından en tolerant genotipin 38 numaralı hat olduğu tespit edilmiştir. Çalışma sonuçları değerlendirildiğinde 5/7, 30, 57, 38 ve 20 numaralı hatlar düşük hastalık indeks değerleri ve yüksek verim kapasiteleri nedeniyle önerilebilir bulunmuştur.

Anahtar kelimeler: pamuk, *Verticillium dahliae*, genotip, hastalık şiddeti

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