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Original article

Yield and fiber quality traits of cotton (*Gossypium hirsutum* L.) cultivars analyzed by biplot method

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ABSTRACT

Background: Cotton is a vital fiber crop fulfilling global demands for raw materials in the textile sector. Therefore, high-yielding cultivars with superior-quality traits are desired at regional scales. The high-yielding cultivars can be selected by determining their responses to various environmental conditions at different locations over a short or long period. Genotypes, environment, and year significantly alter seed cotton yield and fiber quality. Therefore, determining the response to various environmental conditions is necessary for selecting high-yielding cultivars with superior fiber quality.

Methods: This study determined the yield and fiber quality traits of 3 cotton cultivars (i.e., 'DP396', 'BA440' and 'Teksa 415') at five different locations (i.e., Tepe, Boztepe, Bozçalı, Köseli and GAP International Agricultural Research and Training Center) in southeastern Anatolia, Turkey for 3 years (2019, 2020, and 2021). Data relating to seed cotton yield and fiber quality traits were collected and relationships of these traits were determined by biplot analysis.

Results: Cultivars $\times$ traits relationship indicated that 'DP396' was the most stable cultivar with the highest seed cotton yield. Similarly, 'BA440' cultivar was associated with quality characteristics. Sector analysis divided the yield and quality traits into three different groups. The locations $\times$ traits relationship indicated that the examined traits differed according to the locations. Tepe location was in the center in terms of quality and seed yield, whereas Bozçalı location had superior quality traits. Likewise, Boztepe location resulted in higher values of seed and fiber yield, and number of bolls per plant. The studied characteristics varied among the years, and higher values of seed and fiber yields, and the number of bolls per plant were recorded during 2019. On the other hand, superior fiber quality traits were noted during 2021.

Conclusions: It is concluded that 'DP396' was the most stable cultivar for seed cotton yield, whereas 'BA440' was stable for quality traits. Therefore, these cultivars can be used in the studied locations to increase yield and fiber quality. Furthermore, these cultivars could be utilized in the breeding programs for developing high-yielding and better fiber quality producing genotypes in the future.

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1. Introduction

Cotton (*Gossypium hirsutum* L.) is one of the most extensively used textile raw materials around the world. Cotton plays a significant economic role in global economy because of its widespread use in textile industry, and provision of job opportunities in the

countries where it is grown (Khan, 2013). Fiber produced by cotton serves as a raw material for the textile, seeds for oil extraction, and seed cake is utilized in the feed industries. Similarly, the stalks are utilized in the paper industry; thus, it is used for various purposes. The global population increase is also raising the demands for cotton production (Sarwar et al., 2021). The increase in global population and living standards have increased the importance of cotton. Turkey ranks 6th globally in terms of cotton production (815,000 tons annual production), and 4th in terms of cotton consumption after China, India, and Pakistan (Çoban et al., 2016).

Increasing the income from the unit area is necessary for sustainability of cotton farming. Sustainable cotton production might benefit from increased yield per acre, improved fiber quality, lower production costs, and farmer-friendly support policies. Fiber

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quality traits such as color and micronaire are readily affected by environmental conditions and breeding techniques compared with the genetic structure of cotton cultivars (Gul et al., 2014). Similarly, fiber length is also affected by adverse environmental conditions during boll formation phase (Pretorius et al., 2015).

Restricted cotton cultivation areas and ongoing increase in cotton consumption necessitated that cotton output should be enhanced. This requires farmers to produce higher quantity and quality from the unit area. The genetic potential of cultivars, environmental factors, and production methods influence the product's quantity and quality. Regardless of a variety's potential, environmental factors will have a significant impact on the quantity and quality of the crop produce. A variety that is successful in one location will not be able to retain the same productivity or quality features in a different location or under changing environmental circumstances (Yuksekkaya, 2002).

All breeding programs strive to produce cultivars with high yield and quality potential while exhibiting minimal variation in different environments. It is crucial to concentrate on the selection of stable genotypes that interact less with their growing environment to accomplish this aim. Since stability or minimum interaction with the environment is a genetic trait, studies may be planned to select the stable genotypes. Selection of the varieties with higher stability would help in sustainable production over large areas (Baloch et al., 2015; Orawu et al., 2017).

The assessments of quality heavily rely on interactions, which are the link between genotypes and various environmental variables. If a cultivar exhibits significant genotype $\times$ environment, genotype $\times$ years, and genotype $\times$ environment $\times$ years interactions, it is impossible to measure the genetic variation accurately, leading to inaccurate assessments. When more than one variety is tested and compared at different locations, there are differences in the ranking of quality criteria at each location. In addition to the qualitative performance of the variety, it is essential to determine if the variety is stable in terms of quality (Gul et al., 2016).

Since cotton yield, yield components, and fiber quality traits are quantitatively inherited, and environmental factors exert a significant impact on these traits. Determining the general and specific adaptability of cultivars and monitoring the yield and quality performance of cultivars and candidate cultivar under various environmental circumstances is one of the crucial phases of plant breeding (Iqbal et al., 2018). Stability is characterized as the general adaptability of a genotype, which demonstrates strong performance under diverse environments. On the other hand, special adaptability is defined as good performance in a single environment (Ali et al., 2017).

Stability is significantly affected by environmental conditions and characteristics of genotypes. Therefore, researchers use a wide variety of approaches to uncover the influence of genotype, environment, and the interplay of these two factors on stability. Genotype by environment (GE) analysis is one such method since it provides a means of quantifying and visualizing GE, which is crucial for the development of variety (Mukoyi et al., 2018; Peixoto et al., 2022). The GE interaction has a significant effect on genetic characteristics of genotypes and used for the evaluation of superior varieties (van Eeuwijk, et al., 2016; Li et al., 2017). The GGE biplot

model is highly suitable for identifying environmental groups, ideal environments, and best genotypes for the most suitable environment; This method has been used by several researchers to reveal the effect of GE interaction in different plant species (Farias et al., 2016). However, it has not been applied to upland cotton in Turkey. The evaluation of test locations requires integrating the genotype (G) effect with genotype by environment interaction (GEI) as in GGE biplot method (Yan, 2001; Hu et al., 2014). For this reason, GGE biplot is used to identify the effect of variety, location, and their interactions on the stability of the tested genotypes.

The major objective of this study was to determine GE interaction among yield and fiber quality traits of three cotton cultivars at five different locations. It was hypothesized that the cultivars will exhibit significant GE interactions. The results of the study will help to select the stable cultivars for different locations based on GE biplot analysis.

2. Materials and methods

This study was conducted during 2019, 2020, and 2021 at five locations (Tepe, Boztepe, Bozçalı, Köseli and GAP International Agricultural Research and Training Center) in the southeastern Anatolia region, Turkey where cotton is intensively produced. Three commercial common cultivars (i.e., 'DP396', 'BA440' and 'TYS 415') were included in the study. The background information on the experimental sites are given in Table 1. The longer-term average climate data of the studied locations and weather attributes during the experimental period are given in Table 2. The soil properties of the experimental sites are given in Tables 3 and 4.

The experiment was conducted at Boztepe and GAP International Agricultural Research and Training Center Diyarbakır during 2019, Tepe and Köseli during 2020, and Bozçalı locations in 2021. Deep ploughing and herbicide application was done during November of each year. In all years, cotton received 5–6 irrigations by drip irrigation method. Based on the soil analysis, 310 kg diammonium phosphate (DAP 18–46–0) kg/ha, 90 kg potassium sulfate (51% K₂O), 30 kg magnesium sulfate (15% MgO), 330 kg/ha ammonium sulphate (21% N) before first irrigation and 500 kg/ha ammonium sulphate (21% N) were applied during flowering and boll formation periods. The study was carried out under farmer conditions with 10 plant-to-plant spacing, and 70 cm row-to-row spacing. Sowing was done on 15.04.2019, 05.04.2020 and 10.04.2021. Sampling was done on 19.10.2019, 20.10.2020 and 03.10.2021.

The study was carried out under farmer conditions with random plant selection from 30 ha. The plants with all their bolls opened were selected from an area of 1 m². All bolls in each position of woody and fruiting branches were collected and bagged separately. The yield and quality values of the bolls in each position were weighed separately and the fiber quality parameters were measured in the HVI 1000 analyzer.

Moreover, seed cotton yield (YLD), fiber yield (FYLD), number bolls per plant (NCoc), hundred seed weight (HGW), ginning percentage (GP), fiber fineness (FF), fiber length (FL), fiber strength (FSK), and fiber elongation (ELG) were recorded for each cultivar.

Table 1

Background information on the experimental sites used in the study to determine the yield and fiber quality traits of three cotton cultivars.

Years	Sites	Altitude (m)	Latitude N	Longitude E
2019–2020	GAPIRTAEC	612	37°56'26.14"	40°15'13.07"
	Boztepe	535	37°51'43.24"	40°45'32.55"
	Tepe	535	37°48'48.77"	40°50'10.58"
	Köseli	535	37°50'37.79"	40°37'0.38"
2021	Bozçalı	535	37°50'31.59"	40°45'32.55"

GAPIRTC: GAP International Agricultural Research and Training Center, Diyarbakır.

Table 2

Climatic data of Bismil district (Tepe, Köseli, Bozçalı, Boztepe) and GAP International Agricultural Research and Training Center.

Months	Average precipitation (mm)				Average temperature (°C)				Average humidity (%)					
	2013–2021 (Long term)		Years		2013–2021 (Long term)		Years		2013–2021 (Long term)		Years			
			2019	2020			2021	2019			2020	2021	2019	2020
Bismil district (Tepe, Köseli, Bozçalı, abd Boztepe)														
April	51.5		5.0	2.4	0.1	14.7		12.8	14.3	17.2	67.7	73.3	75.8	49.4
May	44.4		1.9	1.2	0.3	20.2		20.8	19.6	23.8	60.0	56.0	65.0	37.0
June	3.2		0.0	0.0	0.0	26.4		28.4	25.5	27.4	40.6	36.3	46.5	32.8
July	0.6		0.0	0.0	0.0	29.8		28.9	29.4	31.3	36.2	38.1	44.4	34.0
August	1.5		0.0	0.0	0.0	28.9		28.7	28.1	29.8	38.9	43.3	42.6	37.2
September	4.4		0.1	0.0	0.1	24.0		23.4	25.7	24.2	41.8	44.1	40.4	37.8
November	25.4		1.7	0.0	0.3	17.4		18.4	18.3	17.6	51.1	56.7	35.7	39.5
October	27.3		0.3	0.2	0.5	9.5		8.7	10.2	11.0	74.0	69.8	65.7	67.6
Mean	368.2		9.0	3.9	1.3	16.2		21.3	21.4	22.8	60.8	52.2	52.0	41.9
GAP International Agricultural Research and Training Center														
April	64.2		4.9	3.7	0.2	15.4		12.9	14.7	17.2	60.5	78.3	72.4	51.0
May	47.5		1.5	2.4	0.1	21.4		22.1	20.9	24.7	47.6	49.2	53.2	30.4
June	5.9		0.0	0.0	0.0	27.8		29.2	27.4	28.6	29.3	29.2	29.9	25.5
July	0.8		0.0	0.1	0.0	32.0		30.9	32.4	32.7	22.6	23.6	22.4	25.1
August	1.3		0.0	0.0	0.3	31.4		31.6	31.3	30.9	24.1	24.3	20.9	29.3
September	4.7		0.0	0.0	0.0	26.5		26.0	28.8	25.6	28.2	27.2	23.7	31.6
November	33.6		1.3	0.0	0.8	19.1		20.0	20.5	18.8	45.6	51.2	30.5	38.9
October	40.2		0.3	1.8	0.7	10.7		10.5	11.6	11.9	66.2	61.7	67.2	70.2
Mean	447.6		1.0	1.0	0.3	17.7		22.9	23.5	23.8	51.5	43.1	40.0	37.7

Table 3

Soil properties of Boztepe, GAP International Agricultural Research and Training Center and Tepe locations included in the study.

Soil properties	Unit	Methods	Value	Status
Boztepe				
pH	–	Saturation	7.8	Slightly alkaline
Lime	(%)	Calcimetric	15.6	Highly chalky
Salt	(%)	Saturation	0.049	Non-saline
Saturation	(%)	Saturation	73	High
Organic matter	(%)	TS 8336	1.07	Low
Total N	(%)	Kjeldahl	0.096	Sufficient
Plant Beneficial P	(Kg P ₂ O ₅ /ha)	“SOP/T-13 Rev. No:4”	40.03	Low
Plant Beneficial K	(Kg K ₂ O/ha)	A. acetate - ICP	1040.4	High
Extractable Ca	(Kg CaO/ha)	A. acetate - ICP	23250.1	High
Extractable Mg	(Kg MgO/ha)	A. acetate - ICP	2130.6	Sufficient
Plant Available Fe	(ppm)	DTPA-ICP	3.32	Middle
Plant Useful Mn	(ppm)	DTPA-ICP	4.25	High
Plant Available Zn	(ppm)	DTPA-ICP	1.41	Sufficient
Plant Useful Cu	(ppm)	DTPA-ICP	1.08	High
GAP International Agricultural Research and Training Center				
pH	–	Saturation	7.8	Slightly alkaline
Lime	(%)	Calcimetric	14.6	Limy
Salt	(%)	Saturation	0.052	Non-saline
Saturation	(%)	Saturation	74	High
Organic matter	(%)	TS 8336	1.18	Low
Total N	(%)	Kjeldahl	0.092	Sufficient
Plant Beneficial P	(Kg P ₂ O ₅ /ha)	“SOP/T-13 Rev. No:4”	20.56	Very low
Plant Beneficial K	(Kg K ₂ O/ha)	A. acetate - ICP	1200.7	High
Extractable Ca	(Kg CaO/ha)	A. acetate - ICP	23930.3	High
Extractable Mg	(Kg MgO/ha)	A. acetate - ICP	2650.9	Sufficient
Plant Available Fe	(ppm)	DTPA-ICP	3.84	Medium
Plant Useful Mn	(ppm)	DTPA-ICP	4.5	High
Plant Available Zn	(ppm)	DTPA-ICP	1.91	Sufficient
Plant Useful Cu	(ppm)	DTPA-ICP	1.15	High
Tepe				
pH	–	Saturation	7.7	Slightly alkaline
Lime	(%)	Calcimetric	15.4	Highly chalky
Salt	(%)	Saturation	0.086	Non-saline
Saturation	(%)	Saturation	79	High
Organic matter	(%)	TS 8336	1.35	Low
Total N	(%)	Kjeldahl	0.102	Sufficient
Plant Beneficial P	(Kg P ₂ O ₅ /ha)	“SOP/T-13 Rev. No:4”	100.7	Sufficient
Plant Beneficial K	(Kg K ₂ O/ha)	A. acetate - ICP	1610.8	High
Extractable Ca	(Kg CaO/ha)	A. acetate - ICP	26,240	High
Extractable Mg	(Kg MgO/ha)	A. acetate - ICP	2100 0.7	Sufficient
Plant Available Fe	(ppm)	DTPA-ICP	5.32	Sufficient
Plant Useful Mn	(ppm)	DTPA-ICP	6.31	High
Plant Available Zn	(ppm)	DTPA-ICP	2.11	Sufficient
Plant Useful Cu	(ppm)	DTPA-ICP	1.27	High

Table 4

Soil properties of Köseli and Bozçalı locations included in the study.

Soil properties	Unit	Methods	Value	Status
Köseli				
pH	–	Saturation	7.8	Slightly alkaline
Lime	(%)	Calcimetric	20	Highly chalky
Salt	(%)	Saturation	0.041	Non-saline
Saturation	(%)	Saturation	75	High
Organic matter	(%)	TS 8336	0.95	Low
Total N	(%)	Kjeldahl	0.1	Sufficient
Plant available P	(Kg P ₂ O ₅ /ha)	“SOP/T-13 Rev. No:4”	20.08	Low
Plant available K	(Kg K ₂ O/ha)	A. acetate - ICP	1080.9	High
Extractable Ca	(Kg CaO/ha)	A. acetate - ICP	24510.1	High
Extractable Mg	(Kg MgO/ha)	A. acetate - ICP	1880.6	Sufficient
Plant available Fe	(ppm)	DTPA-ICP	5.55	Sufficient
Plant available Mn	(ppm)	DTPA-ICP	5.93	High
Plant available Zn	(ppm)	DTPA-ICP	1.46	Sufficient
Plant available Cu	(ppm)	DTPA-ICP	1.24	High
Bozçalı				
pH	–	Saturation	7.8	Slightly alkaline
Lime	(%)	Calcimetric	7.0	Medium chalky
Salt	(%)	Saturation	0.046	Non-saline
Saturation	(%)	Saturation	71	High
Organic matter	(%)	TS 8336	1.23	Low
Total N	(%)	Kjeldahl	0.09	Low
Plant Beneficial P	(Kg P ₂ O ₅ /ha)	“SOP/T-13 Rev. No:4”	30.86	Low
Plant Beneficial K	(Kg K ₂ O/ha)	A. acetate - ICP	1240.9	High
Extractable Ca	(Kg CaO/ha)	A. acetate - ICP	25550.7	High
Extractable Mg	(Kg MgO/ha)	A. acetate - ICP	2490.1	Sufficient
Plant Available Fe	(ppm)	DTPA-ICP	3.42	Medium
Plant Useful Mn	(ppm)	DTPA-ICP	5.75	High
Plant Available Zn	(ppm)	DTPA-ICP	1.48	Sufficient
Plant Useful Cu	(ppm)	DTPA-ICP	1.26	High

2.1. Statistical analysis (GT, ET, and YT)

The collected data were analyzed by GT biplot method as recommended by Yan and Tinker (2005). The yield-trait interactions were calculated based on mean of locations and years. Biplot analyses were performed using Genstat version 14. The data were visualized for the interpretation of GT (genotype $\times$ trait), ET (environment $\times$ trait) and YT (yield $\times$ trait) using the GGE biplot software. The Fig. 1 was produced based on the performance of each genotype for each trait (GT). Similarly, Fig. 2 was generated based on the performance of environments by traits (ET) and Fig. 3 was generated based on years by traits (YT).

3. Results

The mean data for yield and fiber quality traits of three cotton cultivars across five locations are shown in Table 5. The pair-wise correlation of genotype by environment $\times$ traits are shown in Table 6. These data were used to generate a GT biplot (Fig. 1), ET biplot (Fig. 2) and YT biplot (Fig. 3). In the GT biplot model, PC1 accounted for 68.04% of the variation, whereas PC2 represented 31.96% collectively explaining 100% of the variation. Similarly, in ET biplot model, PC1 accounted for 42.92% of the variation, while PC2 explained 42.31% of the variation making a total 85.24%. Likewise, PC1 of YT biplot model explained 89.77% of the variation, PC2 accounted for 10.23% of the variation making a total of 85.24%. The effect of PC1 is always greater than PC2 in stability analysis. Principal component analysis is applicable in situations when a small number of components explain a substantial percentage of total variation (for example, when the top two to five components justify > 60% of total variance) or when components with eigenvalues larger than one are selected. As a consequence, components with several eigenvalues were selected for the analysis

since they might account for a greater share of the total variance (Groth et al., 2013).

3.1. Genotype by trait (GT) biplot

The relationship between the genotypes and traits are visualized in Fig. 1A. These graphs can be interpreted in two ways (Yan et al., 2000; Yan and Tinker, 2006). The GT biplot graph shows the relationship of two traits, the relationship of a trait with other traits, or the relationship of genotypes by traits using the angles between the vectors of traits. The Pearson correlation between the two attributes is approached by the cosine of the angle between their vectors. Therefore, the biplot technique indicates that there is a positive relationship between the vectors of two traits as the angle value ($>0^\circ$ – $<90^\circ$) gets narrower, and a negative relationship exists as the angle value (90° – $<180^\circ$) gets wider. All interpretations are made according to the angles between the vectors of the traits and the varieties where they are located as traits region.

Information about the overall state of the cultivars in terms of their characteristics may be gleaned from the angle that exists between the vector of a cultivar and the traits. As the angle narrows, it means that the cultivars' performance is high, and the cultivars perform poorly as the angle opens. The length or brevity of the vector of a cultivar indicates the strength or weakness of the cultivar with respect to all parameters. The YLD was positively correlated with FYLD, NCoc, Elg, GP, HSW and FF, while negatively correlated with FSK, FL (Fig. 1A). On the other hand, cultivar 'DP396' was associated with YLD, FYLD and NCoc, 'Teksa 450' with FL, and 'BA440' with other traits, i.e., FSK, Elg, GP, HGW and FF. It was understood that cultivars significantly differed for the studied traits.

Fig. 1B visualizes the effect of traits by biplot polygon which genotype wins where. The axis from the center of the graph is divided by bold lines, and the region separated by both bold lines is called the "sector" and starts at the bottom right of the graph

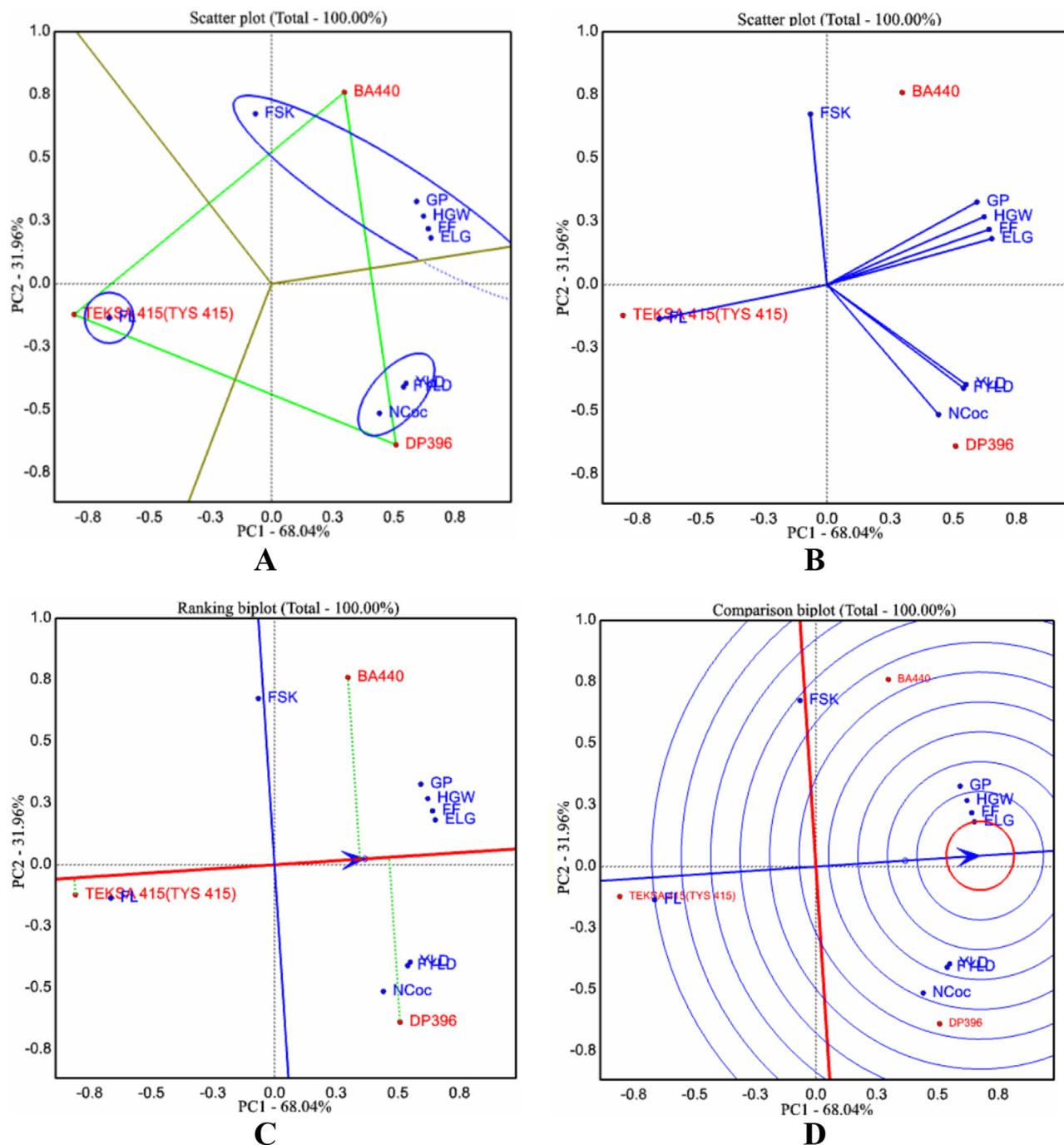


Fig. 1. Genotype by trait interactions of cotton cultivars (A) locations by years, (B) which-won-where/what, (C) stability across years and (D) years and locations. Here, NCoc = number of bolls per plant, YLD = seed cotton yield, FYLD = fiber yield, HSW = hundred seed weight, GP = ginning percentage, FF = fiber fineness, FL = fiber length, FSK = fiber strength (%), ELG = elongation.

sorted by numbers. If the varieties and traits are in the same sector, they are linked (Yan and Tinker, 2006). The Fig. 1B is divided into main 3 sectors. The cultivar 'DP396' was in sector 1 with YLD, FYLD and NCoc, whereas 'Teksa 450' was in sector 2 with FL. Similarly, cultivar 'BA440' was in sector 3 with FSK, Elg, GP, HGW and FF.

Fig. 1C visualized the stability and performance of the cultivars. If the genotypes are located below the vertical axis, these cannot be preferred, and those located above the vertical axis are preferable varieties. The varieties close to or in the middle of the horizontal line (stability line) are stable, while those located away from the horizontal line are unstable (Yan and Rajcan, 2002). Thus, cultivars 'DP396', 'BA440' and 'Teksa 450' were unstable, as they were

located far from the center of the horizontal axis. On the other hand, 'Teksa 450' was unpredictable cultivar as it was located under the vertical axis line. The cultivars 'DP396' and 'BA440' were located above vertical line; therefore, these are preferable based on traits (Fig. 3B).

Fig. 1D presents the representative abilities of the cultivars. A representative "ideal center" is formed, and the most suitable cultivars can be interpreted according to their proximity or distance from this center (Yan and Tinker, 2005). The variety located in the ideal center is the most ideal, those close to the center and above the average vertical axis are preferred. However, the varieties located below the vertical axis (red tick line) are undesirable.

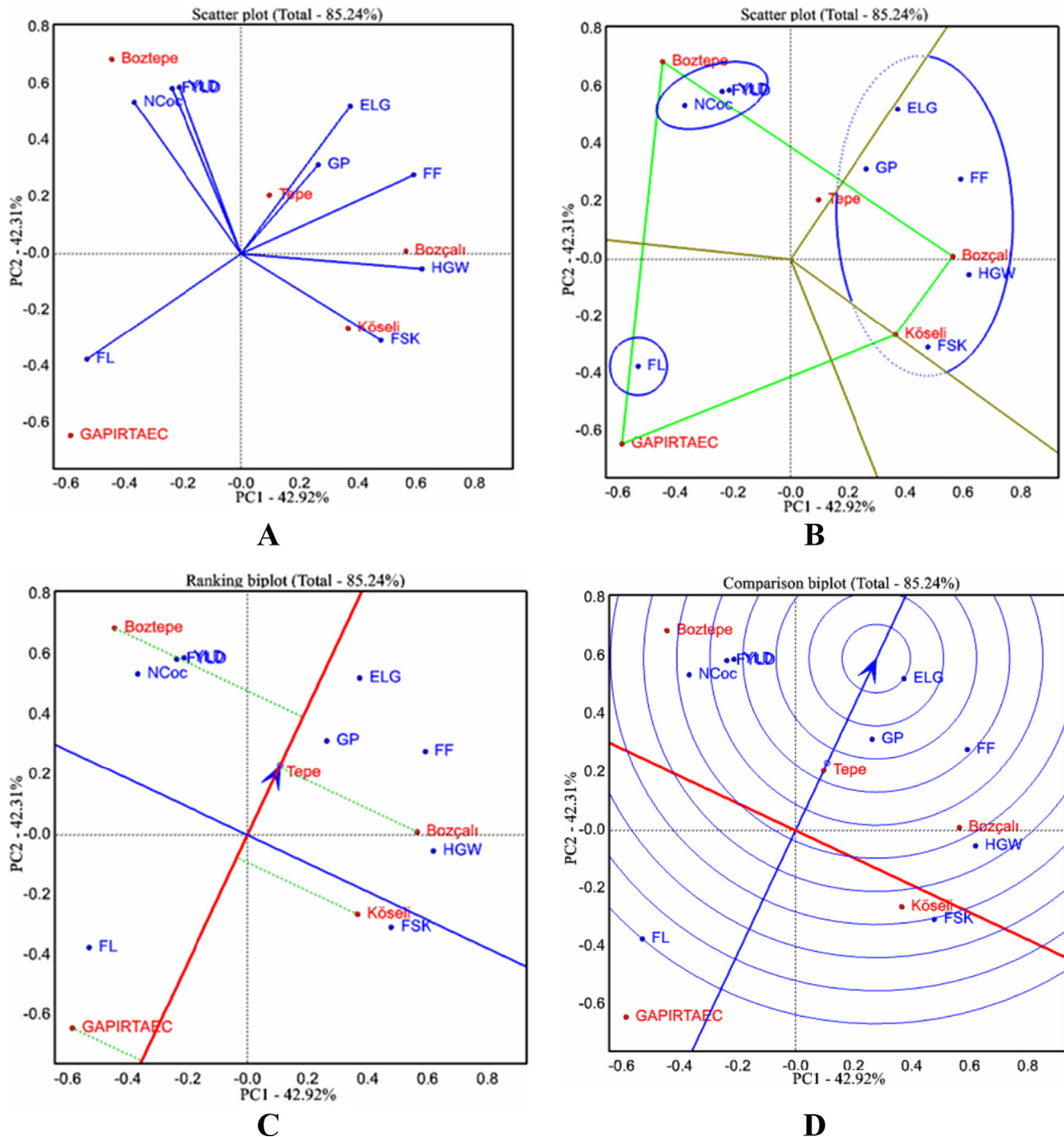


Fig. 2. Environment by trait (ET) biplots across years (A) ET across years, (B) which-won-where of ET across years, (C) ranking biplot of ET across years and (D) comparison biplot of ET across years. Here, NCoc = number of bolls per plant, YLD = seed cotton yield, FYLD = fiber yield, HSW = hundred seed weight, GP = ginning percentage, FF = fiber fineness, FL = fiber length, FSK = fiber strength (%), ELG = elongation.

Based on these explanations, ‘DP396’ and ‘BA440’ were ideal cultivars as they are located on perpendicular axis and near to the “ideal center”, while ‘Teksa 450’ is located under perpendicular axis and far from ideal center; therefore, it is undesirable.

3.2. Environment by traits (ET) biplot

The environments showed high variation based on studied traits (Fig. 2A). The Tepe environment near the center graph meaning that it has moderately desirable, while GAPIRTAEC was far from the center of graph and had only good results for FL. On the other

hand, Boztepe located in the center had good results for YLD, FYLD and NCoc, while Bozçalı and Köseli had good results for HSW and FSK, respectively. It was understood that environment considerably differed for traits, and Tepe was suitable for all traits, while GAPIRTAEC for special trait FL.

Fig. 2B is divided into main 4 sectors and there is no environment or traits located in sector 1. Köseli and Bozçalı environments were located in sector 2 with FSK, HSW, FF, GP and ELG, and Tepe and Boztepe environments were located in sector 3 with YLD, FYLD and NCoc. Similarly, GAPIRTAEC environment was located in sector 4 with only FL trait.

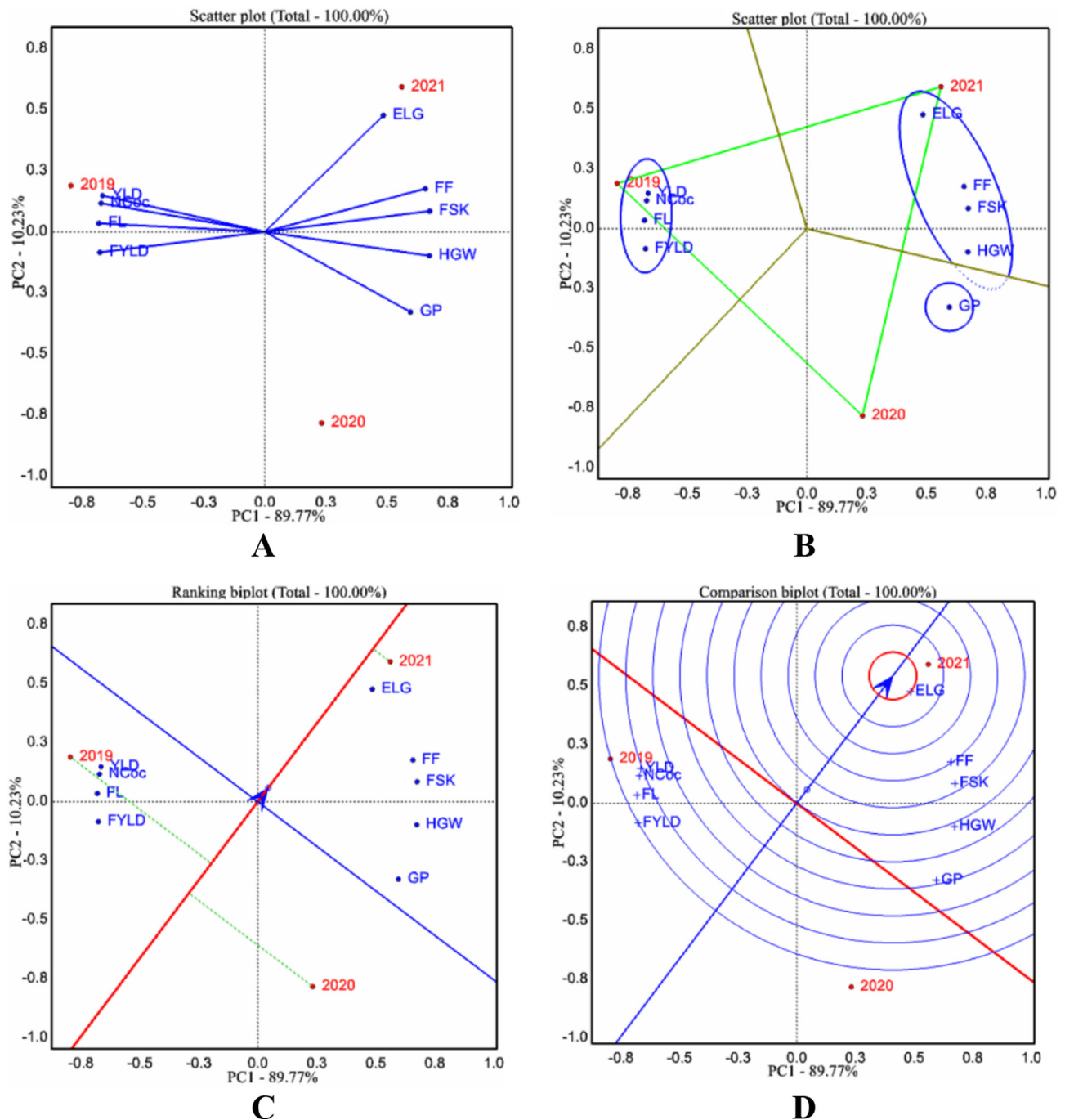


Fig. 3. Year by trait (YT) biplot across different locations (A) relation of YT across environments (B) which-won-where of YT across environments (C) ranking biplot of YT across environments and (D) comparison biplot of YT across environments. Here, NCoc = number of bolls per plant, YLD = seed cotton yield, FYLD = fiber yield, HSW = hundred seed weight, GP = ginning percentage, FF = fiber fineness, FL = fiber length, FSK = fiber strength (%), ELG = elongation.

The representativeness ability refers to the angle between the trait vector and the ATC, the smaller angle indicates more representativeness power. The ATC stand for the axis which passes from the biplot origin and the point representing average of all environments (Yan 2001). Based on the results, Tepe was the most discriminating and representative environments, followed by Boztepe and Bozçalı. The environments GAPIRTAEC and Köseli showed the lowest representativeness and discrimination ability (Fig. 1C).

Tepe was the ideal environment as it was located upon to perpendicular axis and near to the ideal center. Similarly, Bozçalı and Boztepe were the favorable environments, because they were

located on the perpendicular axis. On the other hand, Köseli and GAPIRTAEC were located under perpendicular axis, and far from “ideal center; therefore these were undesirable environments (Fig. 2D).

3.3. Year by traits (YT) biplot

Years were had high variation for the studied traits (Fig. 3A). The 2020 not correlated any traits, while 2019 was correlated with YLD, FYLD, FL and NCoc indicating that these traits were positively affected during 2019. On the other hand, 2021 especially had good results for ELG, HSW FSK, GP and FF.

Table 5

Yield and fiber quality traits of three across three cotton cultivars in different years across five locations included in the study.

Year	Cultivar	Locations	Position	NBol	YLD	FYLD	HSW	GP	FF	FL	FSK	ELG
2019	BA440	Boztepe	FBP 1	66.2	273.0	119.1	7.9	44.0	4.6	29.8	29.3	6.3
2019	BA440	Boztepe	FBP 2	37.4	121.3	53.7	6.7	45.0	4.1	29.4	28.8	6.4
2019	DP396	Boztepe	FBP 1	70.3	281.6	124.4	7.4	44.6	4.4	29.3	29.4	6.1
2019	DP396	Boztepe	FBP 2	26.8	93.8	41.8	7.2	44.8	4.4	27.8	27.1	6.2
2019	Teksa 415	GAPIRTAEC	FBP 1	38.8	159.6	67.8	7.9	43.2	3.9	32.3	32.2	5.6
2019	Teksa 415	GAPIRTAEC	FBP 2	19.5	65.6	28.2	6.3	43.3	3.1	30.9	28.7	5.9
2020	DP396	Tepe	FBP 1	67.4	309.3	134.9	10.2	42.9	4.9	29.2	32.7	6.0
2020	DP396	Tepe	FBP 2	15.7	68.0	31.8	9.2	44.3	4.7	28.9	33.1	6.3
2020	BA440	Köseli	FBP 1	32.3	157.9	70.9	9.9	44.6	4.9	28.6	32.6	5.9
2020	BA440	Köseli	FBP 2	25.4	121.5	55.5	9.6	44.7	4.6	28.9	32.1	6.0
2021	BA440	Bozçalı	FBP 1	43.9	206.2	83.5	10.0	44.2	5.4	28.5	34.6	6.1
2021	BA440	Bozçalı	FBP 2	31.7	157.4	62.6	10.0	44.7	5.2	28.6	33.4	6.4
Mean				39.6	167.9	72.8	8.5	44	5	29	31.2	6.1

NBol = number of bolls per plant, YLD = seed cotton yield, FYLD = fiber yield, HSW = hundred seed weight, GP = ginning percentage, FF = fiber fineness, FL = fiber length, FSK = fiber strength (%), ELG = fiber elongation.

Table 6Pairwise spearman correlation for environment $\times$ traits of different cotton cultivars.

	NBol	YLD	FYLD	HSW	GP	FF	FL	FSK
YLD	0.96**							
FYLD	0.97**	0.99**						
HGW	0.04 ^{ns}	0.27 ^{ns}	0.25 ^{ns}					
GP	-0.24 ^{ns}	-0.28 ^{ns}	-0.27 ^{ns}	-0.01 ^{ns}				
FF	0.24 ^{ns}	0.40 ^{ns}	0.38 ^{ns}	0.83**	0.33 ^{ns}			
FL	0.07 ^{ns}	0.00 ^{ns}	0.00 ^{ns}	-0.42 ^{ns}	-0.65*	-0.68*		
FL	-0.05 ^{ns}	0.15 ^{ns}	0.11 ^{ns}	0.87**	-0.16 ^{ns}	0.63*	-0.08 ^{ns}	
ELG	0.05 ^{ns}	0.01 ^{ns}	0.01 ^{ns}	0.07 ^{ns}	0.63*	0.44 ^{ns}	-0.65*	-0.09 ^{ns}

** = $p < 0.01$, * = $p < 0.05$, ns = non-significant, NBol = number of bolls per plant, YLD = seed cotton yield, FYLD = fiber yield, HSW = hundred seed weight, GP = ginning percentage, FF = fiber fineness, FL = fiber length, FSK = fiber strength (%).

Fig. 3B is divided into main 3 sectors where 2020 is located in sector 1 with GP. Similarly, 2021 is located in sector 2 with HGW, FF, FSK and ELG, and 2019 is located in sector 3 with YLD, FYLD NCoc and FL. Therefore, 2019 was good for yield and fiber yield and traits which correlated with yield, and 2021 had good results of quality traits.

The year of 2021 was the most discriminating and representative conditions. On the other hand, the other years showed the lowest representativeness and discrimination ability to the traits (Fig. 3C).

The year 2021 had ideal conditions as it is located upon to perpendicular axis and near to the ideal center. On the other hand, other two years located under perpendicular axis, and far from ideal center; therefore, these are undesirable (Fig. 3D).

4. Discussion

Determination of the high-yielding varieties with the highest quality can be achieved by determining the most suitable environments. Yield and quality of many plants are affected by environmental conditions (Yan, 2014). In addition, GT, ET, and YT interactions should be clearly revealed. A realistic strategy is to see a single variety, environment or year at acceptable levels for more than one trait (Xu et al., 2017). Therefore, in recent years, many researchers evaluated genotypes based on multiple traits in different plants with GT, ET, and YT (Yan and Tinker, 2006, Kendal, 2019; Sofi et al., 2021). Since there is a negative relationship between yield and quality characteristics in cotton, and this relationship may vary depending on environmental conditions (Luo et al., 2015). Therefore, it is necessary to determine the ET and YT relationships to determine high-yielding and high-quality varieties that adapt to all environments.

In this study, tested cultivars varied depending on the multi-traits. It was noted that the cultivar 'DP396' produced higher YLD

and FYLD and NCoc, whereas cultivar 'BA440' had better HSW, and other quality criteria. Likewise, 'Teksa 450' cultivar has better FL (Fig. 1). The varieties close to the ideal center can be used as parents and preferred more in breeding programs, while varieties far from the ideal center can reduce breeding costs by being introduced in the early period in breeding studies (Ali et al., 2018). Peixoto et al. (2022) showed that, based on the correlation, GT biplot may be thought of as a strong tool for examining the relationship between characteristics, offering a graphical depiction of the genotypes and traits studied. According to Mukoyi et al. (2018), the existence of considerable GE and the correlation of features raises the need for cotton breeding to incorporate a selection index. According to Teodoro et al. (2018), cultivars are selected by farmers for more than simply their high grain production; other traits such as FL and SFI are critical to improving quality. GT is derived from multivariate approaches since genotype performance is assessed based on various attributes, as noted by Xu et al. (2017) and Oliveira et al (2018). This enables the identification of better genotypes that include all desirable traits.

This study found that the traits vary depending on the environment. Tepe location had satisfactory results for all traits, because it was located in the center of all trait vectors. Similarly, Boztepe location has good results for YLD, FYLD and NCoc, whereas Köseli, Bozçalı and GAPIRTAEC were good for specific traits (Fig. 2). Three large environmental groups were formed depending on the environmental conditions in the current study. Mare et al. (2020) selected good varieties based on high-yield and stability under diverse environments. Ali et al. (2017) indicated the presence of the mega-environments could be confirmed by conducting experiments through several years and locations. Xu et al. (2017) noted that the distinction of mega-environments is consistent with the climatic conditions of the locations. Orawu et al. (2017) reported that mega-environment describes the separation of a crop growing area into different target zones.

In YT interaction, traits varied among years and 2019 had good for YLD, FYLD, FL and NCoc. Similarly 2021 had good results for ELG, FF, FSK, and HSW, while 2020 proved specific for GP (Fig. 3). The study indicated three mega-environments among years. Darawseh et al. (2022) reported that year effect was two to six times greater than environment. As a result, the year effect was identified as an important source of variation in all quality traits cotton. Imtiyaz et al. (2017) determined that the variation was mostly managed by the environment followed by years and genotypes. Unay et al. (2004) reported that the differences between environments (years/locations) and genotypes are very important for yield characteristics.

Three main groups were formed in correlation among studied traits in the current study. YLD, NCoc and FYLD were in the same group and positively correlated (Table 6). The ELG, HSW, FF and GP were included in second group, and they were positively correlated. On the other hand, FL and FSK were in the third group, and a direct relationship could not be determined with other traits (Figs. 1-3). Chapepa et al. (2020) discovered a substantial relationship between seed yield and the quantity of bolls per plant. The quantity of bolls per plant may also be used for indirect selection. Because it has a big and positive relationship with cotton fiber production, the number of bolls per plant has a major impact on fiber yield. It is preferable to choose types with more bolls per plant. Because of the positive relationship between this characteristic and yield, Chaudhari et al. (2017) and Pujer et al. (2014) concluded that the quantity of bolls per plant is critical to improving seed cotton output. The results of Rajeev et al. (2016) demonstrated a substantial positive association between yield and boll number. According to Nawaz et al. (2019), there was a positive relationship between fiber length and strength, with an increase in fiber length corresponding to an increase in fiber strength. Rathinavel (2018) discovered that desirable quality features such as fiber uniformity and strength were lacking.

5. Conclusion

The cultivars by traits biplot indicated that 'DP396' was the most stable cultivar for seed cotton yield, and 'BA440' for fiber quality. On the other hand, the environment by traits relationship indicated that Tepe was a better location for fiber quality and seed yield, Bozçalı for quality characteristics, and Boztepe for seed and fiber yield and number of bolls. Therefore, 'DP396', and 'BA440' can be used for higher seed cotton yield and better fiber quality, respectively in southeastern Anatolia region of Turkey.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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