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GENOTYPE X ENVIRONMENT INTERACTION AND GRAIN YIELD STABILITY OF HYBRID POPCORNS EVALUATED IN DIFFERENT CLIMATIC CONDITIONS OF TURKEY

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ABSTRACT

The research was conducted to determine the grain yield and stability of popcorn hybrids grown in four different climatical conditions in 2016 and 2017 growing seasons. The experiments were conducted in 8x8 triple lattice design with three replications using 128 candidate popcorn hybrids and 5 commercial standard varieties. Mean popcorn yields of genotypes in Izmir, Isparta, Samsun, Cankırı/Amasya for 2016 and 2017 were 5.40-5.51 t ha^{-1} and 5.41-6.12 t ha^{-1}, 5.74-5.75 t ha^{-1} and 5.49-5.11 t ha^{-1}, respectively. The results indicated that 2015-31, 2016-31, 2016-51 and 2015-59 popcorn hybrids had high yield potential. The stability analysis based on the b, r^2 and S_d^2 values showed that 2015-22, 2015-28 and 2015-102 genotypes were the most stable hybrid determined in the first year. In the second year, the genotypes 2016-5, 2016-52, 2016-59 and 2016-6 apparent with the high adaptation ability.

Keywords: Adaptation, grain yield, popcorn, stability analysis

INTRODUCTION

Popcorn (*Zea mays everta* Sturt.) is one of the oldest maize variety consumed as snack food throughout the world as well as in Turkey. The shape and size of flakes after kernel popping are the most important character that distinguishes the popcorn from other maize types (Pajic, 2007). The popcorn consumption has sharply increased after 1980's following the opening of shopping centers and cinemas in Turkey (Ozturk et al., 2017). The popcorn production takes place almost in 10.000 ha in Turkey while the amount of popcorn produced is not enough to meet the demand of the country (Oz and Kapar, 2011). Despite the increasing trend in cultivation of popcorn, the seed cost in Turkey is still higher than other maize types (Erdal et al., 2018).

Different popcorn varieties can be successfully grown in almost all regions of Turkey depending on length of growing season, amount of rainfall, temperature and soil fertility. Open-pollinated genotypes are used by local farmers. However, hybrid varieties of popcorn were preferred by professional popcorn producers due to higher yields and better-quality traits for large production fields. Fourteen national popcorn hybrids have been registered by the Variety Registration and Seed Certification Center of Turkey as of 2020 (TTSM, 2020). However, the parents of only a few of the registered popcorn varieties were originally produced in Turkey, and the most of them were belonged to the foreign countries. Wide genetic diversity has been reported among popcorn germplasms in Turkey (Ilarslan et al., 2011; Ozturk et al., 2017). The popcorn cultivation in Turkey suffers from low grain yield and low acceptability to national cultivars. Therefore, new national popcorn hybrids are needed to be developed by the popcorn breeders to meet the demand of high yield popcorn varieties of the country.

Environmental factors such as precipitation and temperature significantly affect the yield of popcorn (Oz and Kapar, 2011), therefore adaptation ability of popcorn varieties varies depending on ecological conditions of the regions (Ziegler and Ashman, 1994). The main target of the breeders is to develop field crop cultivars that are suitable for all environmental conditions or least affected by the environmental variations. An ideal variety should have high yielding potential and shows little yield variation in different environments. Adaptation of a genotype to different environmental conditions indicates the success of a breeding program (Bozoglu and Gulumser, 2000). Therefore, the performance in the interaction of genotype x environment along with the mean performance of a genotype are assessed in breeding programs (Erdal et al., 2012). Several methods have been proposed to determine the stability of genotypes. The model proposed by Eberhart and Russell (1996) assesses the stability of genotypes under various environmental conditions, and the deviation from the mean values of a location is used to measure the stability of a genotype.

This study aimed to (i) evaluate the grain yield performances of 118 national popcorn hybrids under four different climatic conditions, (ii) determine the best popcorn hybrids for each location, (iii) to determine the stable hybrids with high grain yield in various environments.

MATERIALS AND METHODS

One hundred and eighteen popcorn hybrids and five commercial varieties (Antcin 98, Baharcin, Elacin, Nermincin and SH9201) as check were used in the study. Fifty-nine crosses out of 118 hybrids obtained in 2015 were used in 2016, and these crosses were tested in 2017 in four different climatic regions of Turkey. The experiments were conducted in the Black Sea Agricultural Research Institute (KTAE) in Samsun (41°23'N, 36°50'E Northern Turkey), University of Applied Sciences, Faculty of Agriculture (IUFA) in Isparta (37°50'N, 30°52'E Mediterranean region), Cankırı Karatekin University (CKU) in Cankırı (40°32'N, 33°35' central Anatolia), and Poltar Agricultural Products Limited Company (IPT) in Izmir (39° 8'N, 27° 13' Aegean region). Suluova (AS) in Amasya (40°85'N, 35°66' Middle Anatolia) was used in 2017 instead of CKU.

Some of soil physical and chemical characteristics of the experimental fields were given in Table 1. Soil samples were taken from a depth of 0-20 cm in the experimental areas. Physical and chemical analyzes were carried out in the laboratories of KTAEM Soil Department. When soil properties were evaluated together, similar results were obtained from the trial areas in terms of soil reaction, soil structure, salinity, potassium and organic matter contents. It was determined as slightly alkaline in terms of pH, in clayey-loam structure, without salt, with high potassium content and low organic matter content. In terms of phosphorus content, Amasya location was determined as moderate, less or less than other trial areas, Isparta more calcareous in terms of lime content, and medium lime in other trial areas.

Table 1. Soil properties of the experimental fields located in different ecological regions

	2016				2017			
Parameter	Samsun	Isparta	Cankırı	Izmir	Samsun	Isparta	Amasya	Izmir
Soil texture	Clay-loam	Clay-loam	Clay-loam	Clay-loam	Clay-loam	Clay-loam	Clay-loam	Clay-loam
pH	7.8	8.10	7.83	7.75	7.85	8.02	7.62	7.8
P_2O_5 (kg ha^{-1})	25	28	28	31	25	31	78	29
K_2O (kg ha^{-1})	940	850	990	950	940	880	600	920
Organic Matter (%)	1.76	1.78	1.99	1.88	1.81	1.82	2.05	1.8
Lime (%)	6.76	22.15	10.59	20.5	6.85	21.50	7.93	18.4
Salinity (%)	0.054	0.059	0.062	0.058	0.054	0.059	0.054	0.056

Mean temperature values of Samsun in 2016 and 2017 were 14.6 and 14.1 °C, respectively which were very similar to the mean temperatures of the long term data. In contrast to the mean yearly temperature, monthly temperature values were different from the temperatures of the long term data. For example; mean temperature of June and August during the experimental years was 1°C higher than that of the long term values. The temperature in May of 2016 was 1 °C higher, while the temperature was 1 °C lower in 2017 compared to the long term data. Means of temperature of Izmir in 2016 (17.2 °C) and 2017 (16.7 °C) was higher than the other three locations. The average temperature in Izmir was higher than that of the long term. Long term average temperature in Isparta (12.1 °C) was lower the other three locations. The mean temperature in 2016 (13.1 °C) and 2017 (12.5 °C) was higher than the mean temperature of the long term. The mean temperature in Cankırı (13.0 °C) for 2016 and Amasya (12.3 °C) for 2017 was similar to those recorded in the long term values (Table 2).

Mean precipitation values in Samsun for 2016 and 2017 were 1106.4 and 758.2 mm, respectively. Mean of precipitation in 2016 was higher and in 2017 was lower than the precipitation recorded in the long term (Table 3). Means precipitation values in Izmir for 2016 and 2017 were 531 and 697.4 mm respectively. The average precipitation in 2016 was lower and in 2017 was higher than the precipitation of the long term (Table 3). The average precipitation in Isparta for long term (517.6 mm) was lower compared to the precipitation in 2016 (521.3 mm) and higher than that recorded in 2017 (467.2 mm) respectively. The average precipitation in Cankırı (439.5 mm) for 2016 and in Amasya (322.2 mm) for 2017 were similar to the precipitations recorded in the long term (Table 3).

The experiments were designed in 8x8 triple lattices with three replications by using 59 candidate popcorn hybrids and 5 commercial standard varieties for each year. The length of rows in each plot was 5.0 m, and inter row and intra row distances were 0.70 and 0.18 m, respectively. Popcorn seeds were sown in the 4th week of April in IPT, in the 1st week of May in KTAE, IUFA and CKU/AS. Fertilizer application rate was 200 kg nitrogen ha^{-1} and 80 kg phosphorus ha^{-1} based on soil analysis given in Table 1. All phosphorus and half of the nitrogen were applied before sowing. The rest of nitrogen was applied at the sixth leaf stage with drip irrigation system.

Table 2. Temperature data of the experimental locations

Months	Samsun-Carsamba			Izmir-Bergama			Isparta			Cankırı-Kızılırmak		Amasya- Suluova	
	Long term	2016	2017	Long term	2016	2017	Long term	2016	2017	Long term	2016	Long term	2017
January	6.7	6.2	4.8	6.7	6.3	4.1	1.7	1.3	-0.8	2.2	2.5	2.1	0.7
February	7.1	10.4	6.1	7.4	11.9	8.3	2.8	7.3	3.0	4.9	4.3	5.3	3.0
March	8.5	10.0	8.6	9.9	11.8	11.8	6.1	7.6	7.3	7.6	7.5	8.3	8.3
April	11.2	13.7	9.9	14.4	17.7	14.9	10.6	14.0	10.6	12.8	12.2	12.1	10.9
May	15.7	16.3	14.8	19.5	19.2	19.9	15.2	14.6	14.9	17.3	16.5	16.5	15.5
June	20.3	21.4	20.1	24.4	26.0	25.1	19.9	21.6	20.1	21.0	22.0	19.7	19.8
July	23.2	23.5	23.1	26.9	27.8	27.5	23.5	25.0	25.2	23.9	24.3	22.1	23.0
August	23.9	24.7	24.5	26.7	28.0	27.1	23.3	24.4	23.8	24.4	23.2	23.2	23.7
September	20.0	19.5	21.0	22.7	23.2	23.7	18.8	18.9	21.0	20.2	20.2	18.9	20.5
October	15.6	14.6	14.6	17.4	17.6	17.0	13.2	14.8	13.0	14.1	12.5	12.5	11.8
November	11.2	10.6	11.2	11.9	12.2	11.7	7.3	7.2	6.7	7.7	7.8	7.0	6.4
December	7.9	4.5	9.9	8.3	4.8	9.6	3.3	0.3	5.0	2.8	3.0	2.4	4.6
Average	14.3	14.6	14.1	16.4	17.2	16.7	12.1	13.1	12.5	13.2	13.0	12.5	12.3

Table 3. Precipitation data of the experimental locations

Months	Samsun-Carsamba			Izmir-Bergama			Isparta			Cankırı-Kızılırmak		Amasya-Suluova	
	Long term	2016	2017	Long term	2016	2017	Long term	2016	2017	Long term	2016	Long term	2017
January	101.0	140.0	133.4	95.5	180.2	210.2	66.2	98.0	58.8	37.0	38.2	23.7	5.0
February	51.6	31.6	20.6	80.9	54.0	50.8	56.5	31.8	3.6	29.1	30.4	14.6	3.0
March	81.5	108.1	57.8	66.4	53.4	75.0	55.5	60.4	76.0	35.0	34.3	43.5	41.5
April	49.1	44.4	81.8	53.3	12.4	38.2	55.3	47.6	24.5	49.8	52.5	31.8	51.4
May	54.0	191.8	59.0	30.3	62.2	54.8	52.4	88.6	139.5	53.7	57.0	67.0	62.0
June	63.3	98.5	110.6	16.7	21.8	14.2	29.7	13.0	26.4	39.4	50.2	58.0	51.1
July	35.1	50.9	1.6	8.7	0.0	13.8	18.3	25.5	10.7	21.4	22.5	4.4	0.2
August	32.3	59.0	15.0	7.5	0.0	1.8	16.3	47.5	16.8	18.4	20.2	7.1	2.2
September	53.4	108.2	7.4	20.1	2.0	0.2	17.5	32.3	8.5	16.5	18.5	15.3	8.1
October	102.2	39.6	58.0	50.4	4.6	50.4	36.4	1.6	33.2	32.0	31.7	19.6	22.1
November	92.2	94.3	41.8	95.2	129.8	61.0	46.0	49.0	38.5	30.8	35.8	15.7	31.7
December	103.4	140.0	171.2	120.9	10.6	127.0	67.5	26.0	30.7	45.7	48.2	23.2	43.9
Total	819.1	1106.4	758.2	645.9	531.0	697.4	517.6	521.3	467.2	408.9	439.5	323.9	322.2

Since the plants reached to the harvest in different dates, the harvest dates in locations were different. Crops were harvested manually in the 4th week of September in IPT, in the 1st week of October in IUFA, in the 3th week of October in KTAE, and in the 1st week of November in CKU/AS. Kernel moisture content of popcorn was adjusted to 15% to determine the grain yield (GY) using the following equation;

$$GY = \ Plot\ weight\ x \ \ [(100 - \ grain\ moisture\ \% \ /85) \ x \ ((Grain\ /\ ear\ ratio)/100)]$$

The differences in grain yield data among the experimental locations were evaluated by a variance analysis (ANOVA) using Statistical Package Software. Duncan's multiple range test (Little and Hills, 1978) was used to differentiate the means in case ANOVA indicated significant differences. The stability analysis was applied to evaluate the genotype×location interaction as described by Eberhart and Russell (Nascimento et al., 2013).

RESULTS

The results of ANOVA indicated significant differences in grain yields of popcorn hybrids among the experimental locations both for 2016 and 2017 (Table 4). The mean grain yields of popcorn hybrids were presented in Table 5. Since the ANOVA denoted significant differences in the grain yields of hybrids among the locations, the each location were evaluated separately for both 2016 and 2017 (Table 5).

Table 4. The results of variance analysis for grain yield in different locations

Source	Prob>F	
	2016	2017
Replication	0.9064	0.0045
Location	<0.0001	0.03986
Genotype	<0.0001	<0.0001
Genotype × location	<0.0001	<0.0001

Grain yield performances of popcorn hybrids in experimental locations were different. The highest mean grain yield (5.74 t ha^{-1}) was obtained at Samsun in 2016. The mean grain yields obtained in Izmir, Isparta and Cankırı in 2016 were 5.40, 5.41 and 5.49 t ha^{-1}, respectively (Table 5). While the lowest grain yield in 2017 was recorded in Amasya (5.11 t ha^{-1}), the highest grain yield was obtained in Isparta (6.12 t ha^{-1}) in 2017 (Table 5). Seventeen popcorn hybrids in Amasya had a lower grain than the commercial varieties in 2016, while the grain yields of forty-eight popcorn hybrids in Isparta were higher than the commercial checks (Table 5).

The grain yields of hybrids at Izmir in 2016 ranged from 3.42 to 6.60 t ha^{-1} with a mean value of 5.40 t ha^{-1}. The mean grain yield of commercial varieties was 5.39 t ha^{-1}, while the mean value for the tested hybrids was 5.43 t ha^{-1}. The lowest gain yield (3.42 t ha^{-1}) was obtained from 2015-7 hybrid and the highest grain yield (6.60 t ha^{-1}) was recorded in 2015-74 hybrid (Table 5). Thirty-seven tested hybrids had a higher grain yield than the commercial checks, and the mean grain yield of sixteen tested hybrids was higher compared to the overall mean grain yield obtained in the experiments. In 2017, mean grain yield of hybrids was 5.51 t ha^{-1} and changed from 4.11 to 6.80 t ha^{-1}. The lowest (4.11 t ha^{-1}) and the highest (6.80 t ha^{-1}) grain yield values were recorded in 2016-7 and 2016-14 hybrids (Table 5). Thirty-one tested hybrids had a higher grain yield than the commercial checks, and mean grain yield of twenty-five tested hybrids was higher grain compared to the mean grain yield recorded in the experiments (Table 5).

The mean grain yield of hybrids in Isparta for 2016 was 5.41 t ha^{-1}, and changed from 3.57 t ha^{-1} to 7.07 t ha^{-1}. The mean grain yield of commercial varieties was 4.93 t ha^{-1}, while the mean grain yield of the tested hybrids was 5.46 t ha^{-1}. The lowest and the highest grain yields were obtained in 2015-85 hybrid (3.57t ha^{-1}) and 2015-31 hybrid (7.07 t ha^{-1}). The mean grain yield of forty-eight tested hybrids was higher than that of the commercial checks. The mean grain yield value of thirty-four tested hybrids was higher than the overall mean value of the experiments. In 2017, the mean grain yield of hybrids was 6.12 t ha^{-1} and changed from 4.69 to 7.22 t ha^{-1}. The lowest mean grain yield (4.69 t ha^{-1}) was obtained in 2016-32 hybrid, while the highest grain yield (7.22 t ha^{-1}) was recorded in 2016-51 hybrid (Table 5). The mean grain yield of forty-one tested hybrids was higher than the mean grain yield of the commercial checks, and the mean grain yield of thirty-four tested hybrids was higher compared to the mean grain yield obtained in the experiments (Table 5).

The mean grain yield of hybrids in Samsun for 2016 was 5.74 t ha^{-1}, and the yield ranged from 4.39 to 7.94 t ha^{-1}. The mean grain yield of commercial varieties was 5.63 t ha^{-1}, and the mean yield of the tested hybrids was 5.75 t ha^{-1}. The lowest and the highest grain yields were obtained in 2015-23 hybrid (4.39 t ha^{-1}) and 2015-31 hybrid (7.94 t ha^{-1}). Twenty-six tested hybrids had higher grain yield than the commercial checks. In 2017, mean grain yield of hybrids was 5.75 t ha^{-1} and changed from 4.05 to 7.70 t ha^{-1}. The mean grain yield of commercial varieties was 5.27 t ha^{-1}, while the mean grain yield of tested hybrids was 5.79 t ha^{-1}. The lowest grain yield (4.05 t ha^{-1}) was obtained in 2016-18 hybrid, and the highest grain yield (7.70 t ha^{-1}) was recorded in 2016-31 hybrid. Forty-four tested hybrids had a higher grain yield than the commercial checks, and the mean grain yield of thirty-three tested hybrids was higher than the means grain yield of the experiments (Table 5).

The mean grain yield of hybrids in Cankırı was 5.49 t ha^{-1}, and the value ranged from 3.58 to 7.15 t ha^{-1} in 2016 year. The mean grain yield of commercial varieties was 4.85 t ha^{-1}, while the mean grain yield of the tested hybrids was 5.63 t ha^{-1}. The lowest grain yield (3.58 t ha^{-1}) was obtained in 2015-85 hybrids, and the highest grain yield (7.15 t ha^{-1}) was recorded in 2015-59 hybrid. Forty-six tested hybrids had a higher grain yield than the commercial checks, and the mean grain yield of thirty-two tested hybrids was higher than the mean grain of the experiments. The location of experiment in 2017 was moved to Amasya from Cankırı. The mean grain yield of hybrids in Amasya was 5.11 t ha^{-1} and the grain yield changed from 3.51 to 6.32 t ha^{-1}. The mean grain yield commercial varieties was 5.51 t ha^{-1}, while the mean grain yield of the tested hybrids was 5.07 t ha^{-1}. The lowest and the highest grain yields were obtained in 2016-22 hybrid (3.51 t ha^{-1}) and in 2016-41 hybrid (6.32 t ha^{-1}). Seventeen tested hybrids had a higher grain yield than the grain yield recorded for commercial checks, and the mean grain yield of twenty-nine tested hybrids was higher than mean grain yield of the experiments (Table 5).

Stability Analysis

The method proposed by Eberhart and Russell (1966), which detects and measures the magnitude of genotype x environment interaction, have been widely used due to the easy application and the guidelines to follow (Nascimento et al., 2013). Mean grain yield ($\bar{x}$), regression coefficient (b), coefficient of determination ($R2^{\%}$), squared deviation from regression (s_d^2) and intercept value (a) were used as the stability parameters. The regression coefficient is considered equal to 1 in the stability analysis (Eberhart and Russell, 1966). All varieties included in the study were tested for b = 1, and the varieties that did not differ significantly were considered stable.

Table 5. Mean grain yield (t ha^{-1}) values of popcorn hybrids in different locations

2016					2017				
Genotypes	Izmir	Isparta	Samsun	Cankırı	Genotypes	Izmir	Isparta	Samsun	Amasya
Antcin (st)	5,22 c-q	4,35 s-w	5,21 l-t	4,98 p-z	Antcin (st)	5,51 ı-s	6,23 e-n	5,12 b-t	5,12 g-r
Baharcin (st)	6,16 a-h	5,58 e-r	6,81 a-g	4,81 a-t	Baharcin (st)	5,06 n-y	5,85 k-s	5,04 b-v	5,96 a-e
Elacin (st)	6,54 ab	4,79 n-v	4,90 o-t	4,43 b-x	Elacin (st)	6,07 b-j	5,89 j-s	5,49 n-y	6,03 a-d
Nermincin (st)	6,20 a-g	5,16 j-t	5,69 f-s	4,94 q-z	Nermincin (st)	5,44 j-u	5,47 -w	6,21 c-o	5,25 g-p
SH9201 (st)	6,36 a-d	4,78 o-v	5,52 h-t	4,88 a-q	SH9201 (st)	6,14 a-ı	5,85 k-s	4,52 abc	5,20 g-q
2015-1	4,97g-r	5,62 d-q	5,32 j-t	4,00 abc	2016-1	6,41 a-f	5,57 o-v	6,84 bc	5,61 c-k
2015-10	4,88 l-t	5,57 e-r	5,03 m-t	5,36 l-y	2016-10	6,51 a-e	6,54 b-ı	6,18 c-o	5,07 ı-s
2015-102	4,74 l-t	4,94 l-u	6,28,c-m	5,53 g-t	2016-11	5,57 h-q	6,58 b-h	6,38 b-i	4,98 k-v
2015-107	4,99 f-r	4,71 p-v	5,39 ı-t	7,05 abc	2016-12	5,27 k-v	6,10 f-o	6,00 d-q	5,46 d-n
2015-11	5,94 a-k	6,10 b-ı	4,68 q-t	5,40 l-w	2016-13	6,04 b-j	6,06 g-q	6,64 b-e	4,94 l-w
2015-113	4,68m-u	5,68 d-p	6,17 c-n	5,47 l-u	2016-14	6,80 a	4,95 wx	7,00 ab	5,35 f-o
2015-12	4,64 n-u	3,92 vw	4,44 st	4,49 b-v	2016-15	4,91 q-y	5,64 n-u	4,65 z-c	4,31 b-w
2015-13	3,68 tu	6,50 a-d	5,39 ı-t	6,00 f-t	2016-16	5,66 g-p	6,69 a-f	5,51 n-y	4,84 m-x
2015-14	5,20 d-r	5,18 j-t	6,43 c-l	6,53 a-i	2016-17	6,29 a-g	5,07 u-x	5,66 ı-w	5,70 a-ı
2015-15	5,79 a-o	6,78 ab	7,74 ab	5,50 k-t	2016-18	6,79 a	4,99 vx	4,05 c	3,78 bc
2015-16	630,7 a-e	4,67 o-v	6,69 a-h	3,87 abc	2016-19	5,05 n-y	6,31 d-m	5,69 ı-w	4,40 b-t
2015-17	4,84 l-t	5,55 -r	5,25 k-t	3,87 bc	2016-2	6,67 ab	6,44 b-k	5,87 f-s	6,23 abc
2015-18	5,78 a-o	5,53 e-r	6,95 a-f	5,26 n-z	2016-20	5,03 p-y	6,78 a-e	5,79 h-u	5,03 j-t
2015-19	4,57 o-u	3,65 w	5,04 m-t	5,36 l-x	2016-21	5,72 f-o	5,97 h-s	6,21 c-n	5,76 a-g
2015-2	5,89 a-l	5,57 e-r	5,52 h-t	5,86 d-q	2016-22	5,27 l-v	6,58 b-h	5,32 q-z	3,51 c
2015-20	4,96 h-s	5,70 d-o	5,58 g-t	5,78 e-t	2016-23	5,43 j-u	6,86 a-d	4,79 c-y	4,78 n-y
2015-21	5,38 c-p	6,17 a-f	6,54 b-k	6,79 a-d	2016-24	5,16 n-x	6,61 b-g	5,07 b-u	5,72 a-ı
2015-22	5,94 a-l	5,08 j-t	5,74 e-r	5,16 n-z	2016-25	4,83 s-y	6,27 d-m	6,01 d-q	5,17 g-r
2015-23	5,25 c-q	4,27 t-w	4,39 t	4,94 q-z	2016-26	4,42 yz	6,36 d-l	6,36 b-j	4,56 q-z
2015-24	6,13 a-h	4,85 m-v	5,21 l-t	5,53 h-t	2016-27	6,09 b-j	5,95 ı-s	6,12 c-p	4,96 l-v
2015-25	5,36 c-p	5,26 h-t	7,30 a-d	5,51 ı-t	2016-28	4,70 v-z	5,58 o-v	5,46 o-y	5,60 c-k
2015-26	5,96 a-k	5,73 d-m	6,99 a-e	5,49 l-u	2016-29	5,53 ı-r	6,24 e-n	5,28 q-z	4,08 c-z
2015-27	5,61 a-o	5,07 j-t	5,30 k-t	4,70 b-u	2016-3	5,19 m-x	6,29 d-m	6,54 b-h	5,31 g-p
2015-28	5,49 b-p	5,26 g-s	5,58 g-t	5,51 j-t	2016-30	4,98 p-y	5,60 o-u	5,54 m-y	5,14 g-r
2015-29	5,08 e-r	5,14 j-t	5,77 e-r	5,85 e-r	2016-31	6,58 a-d	6,47 b-j	7,70 a	5,70 a-ı
2015-3	5,50 a-o	5,68 d-o	7,22 a-d	5,82 e-t	2016-32	4,77 u-z	4,69 x	4,80 b-y	4,36 b-u
2015-30	6,26 a-g	5,71 d-n	6,30 c-m	5,41 l-v	2016-33	5,87 e-m	6,15 f-o	6,32 b-k	4,54 r-z
2015-31	5,97 a-k	7,07 a	7,94 a	7,13 ab	2016-34	5,27 k-v	5,76 m-t	5,79 h-v	5,21 g-p
2015-32	4,33 q-u	4,65 r-v	4,76 p-t	5,83 e-s	2016-35	4,57 w-z	6,33 d-m	4,86 b-x	4,15 c-y
2015-33	5,87a-m	5,12 j-t	5,39 e-q	6,25 b-m	2016-36	5,66 g-p	5,37 s-w	6,54 b-h	5,95 a-f
2015-34	6,05 a-ı	5,49 f-r	4,88 q-t	4,36 c-z	2016-37	5,29 k-v	6,50 b-ı	6,01 d-q	5,65 b-k
2015-35	6,16 a-h	6,30 a-e	6,67 a-ı	6,41 a-l	2016-38	5,66 g-p	5,82 l-t	5,57 l-x	5,70 b-j
2015-36	4,91 j-t	5,66 d-p	5,24 k-t	5,42 l-v	2016-39	5,13 n-x	5,96 ı-s	5,98 d-r	4,84 l-x
2015-37	5,99 a-k	5,74 c-l	5,05 m-t	5,60 f-t	2016-4	4,52 xyz	6,42 c-l	5,57 k-x	5,60 c-k
2015-38	5,08 e-r	4,98 k-t	4,91 o-t	5,28 m-z	2016-40	5,46 j-t	6,52 b-i	6,48 b-h	5,91 a-f
2015-4	4,90 k-t	5,84 c-k	6,59 b-j	4,86 a-r	2016-41	5,73 f-n	4,97 w-x	5,23 b-s	6,32 a
2015-42	5,35 c-q	5,84 c-k	5,37 ı-t	4,78 a-t	2016-42	5,58 h-q	5,22 t-x	6,51 b-h	5,47 d-l
2015-5	4,98 ı-t	5,50 d-r	6,25 c-m	5,30 m-z	2016-43	4,87 r-y	6,60 b-g	5,12 b-t	4,71 o-z
2015-50	5,24 c-q	5,54 e-r	4,75 p-t	5,40 l-w	2016-44	5,63 g-p	6,06 g-q	6,10 c-p	5,21 g-p
2015-51	5,56 a-o	5,35 f-s	5,97 d-p	6,42 a-k	2016-45	6,07 b-j	6,30 d-m	5,86 g-t	3,86 abc
2015-54	6,17 a-g	6,64 abc	5,46 h-t	5,47 l-v	2016-46	5,29 k-v	5,89 j-s	4,99 b-w	5,59 c-k
2015-57	6,02 a-k	5,97 b-j	6,01 d-o	5,98 d-p	2016-47	4,78 u-z	5,42 r-w	6,32 b-m	4,91 l-w
2015-58	5,11 e-r	6,17 a-f	4,92 n-t	5,08 p-z	2016-48	4,80 t-y	6,00 h-r	4,66 c-z	4,75 n-y
2015-59	6,53 abc	5,16 j-t	5,47 h-t	7,15 a	2016-49	5,99 c-j	7,01 abc	5,00 b-w	4,66 p-z
2015-6	4,12 r-u	3,99u-w	4,43 t	4,39 b-y	2016-5	6,22 a-h	6,68 a-f	5,94 e-s	5,62 c-k
2015-63	4,98 f-r	5,17 j-t	4,68 p-t	6,46 a-ı	2016-50	5,94 d-k	6,43 c-k	6,18 c-o	4,48 a-s
2015-66	5,54 a-o	5,93 b-j	5,89 e-q	5,84 e-s	2016-51	4,62 v-z	7,22 a	6,58 b-g	6,25 ab
2015-69	6,20 a-g	5,52 f-r	5,19 l-t	6,06 c-o	2016-52	5,54 ı-r	7,03 ab	6,49 b-h	5,11 h-r
2015-7	3,42 u	5,05 k-t	5,20 l-t	6,04 d-p	2016-53	5,22 m-v	6,96 abc	6,28 c-n	4,41 b-t
2015-74	6,60a	5,35 f-s	6,15 d-o	6,55 a-g	2016-54	6,64 abc	6,30 d-m	6,70 bcd	5,01 k-t
2015-79	5,43 b-p	5,24 ı-t	7,21 a-d	6,76 a-e	2016-55	5,04 o-y	6,70 a-f	5,40 p-z	4,22 b-x
2015-8	5,91 a-l	5,18 j-t	5,16 m-t	4,45 b-w	2016-56	5,93 d-l	5,45 q-w	5,48 n-y	4,33 b-v
2015-85	3,78 stu	3,57 w	4,50 rst	3,58 c	2016-57	6,26 a-h	6,56 b-h	5,87 g-t	5,74 a-h
2015-88	6,52 abc	6,17 a-g	6,95 a-e	6,7 a-f	2016-58	6,01 b-j	6,24 e-n	4,40 bc	5,18 g-r
2015-89	5,51 a-o	6,31 a-e	7,45 abc	5,89 d-p	2016-59	5,96 c-k	6,65 a-g	5,99 d-q	4,99 k-u
2015-9	4,38 p-u	5,78 c-k	5,09 m-t	4,67 b-v	2016-6	5,65 g-p	6,10 f-o	5,62 j-w	5,00 k-t
2015-90	5,35 c-q	5,69 d-o	5,36 j-t	5,12 o-z	2016-7	4,11 z	6,07 g-p	5,24 a-r	4,91 l-w
2015-91	5,82 a-n	6,10 b-h	5,48 h-t	6,00 d-p	2016-8	4,77 u-z	6,35 d-l	4,46 bc	5,17 g-r
2015-94	5,41 b-p	5,77 c-l	6,07 d-o	6,18 b-n	2016-9	5,54 ı-r	6,23 e-n	6,61 b-f	5,39 e-n
Mean	5,40	5,41	5,74	5,49	Mean	5,51	6,12	5,75	5,11
Mean of checks	5,39	4,93	5,63	4,85	Mean of check	5,64	5,96	5,27	5,51
Mean of tested Hybrids	5,43	5,46	5,75	5,54	Mean of tested hybrids	5,51	6,14	5,79	5,07
CV (%)	13,2	10,5	13,1	10,05	CV (%)	7,44	5,92	10,12	7,55
LSD	0,95	0,86	0,91	0,92	LSD	0,67	0,59	0,74	0,63
F-value	6,6845**	4,2228**	3,7212**	5,8201*	F-value	6,9591**		7,3240**	7,4646**

**, *: indicate significance at 0.01 and 0.05 levels, respectively, CV: Coefficient of variation,LSD: Least Significant Difference, Means followed by the same letters are not statistically different.

The variance analysis indicated that the effects of location, genotype and genotype × location (environment) interaction on grain yield of popcorn varieties were statistically significant (Table 4).

The mean values and stability parameters of grain yield of popcorn genotypes tested at different locations in 2016 were given in Table 6 and the adaptation classes were shown in Figure 1. The genotypes, which had a higher yield than the overall mean yield, had a regression coefficient and coefficient of determination close to 1.0 and deviation from the regression was not significantly different from zero, were considered stable. The regression coefficient in stability analysis and the lower confidence limits of the mean values were evaluated with a 5% probability (Table 6).

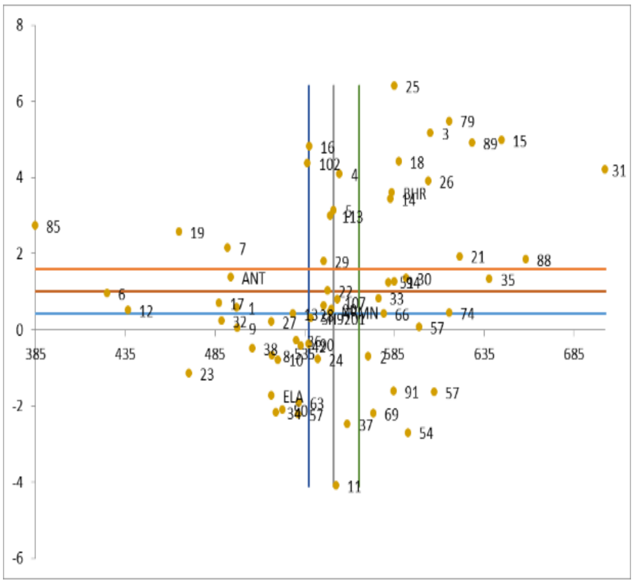

Figure 1. Scattered diagram for grain yield of popcorn hybrids in four different locations in 2016.

The yields of 20 genotypes tested in 2016 were higher than the mean grain yield obtained for the experiments. The confidence interval for grain yield per hectare calculated with a 5% probability ranged from 5.38 to 5.66 t ha^{-1}. The mean grain yield recorded for 2015-66, 2015-69, 2015-33, 2015-2, 2015-107, 2015-4, 2015-37, 2015-11, 2015-20, 2015-22, 2015-5, Nermincin(st), 2015-102, 2015-28, 2015-29, 2015-42, 2015-36, 2015-90, 2015-7, 2015-24, 2015-63 candidate hybrids was considered equal to the mean grain yield of the experiment with a 5% probability. The 2015-22, 2015-28 and 2015-102 popcorn genotypes had a b and R^2 values close to 1.0 and the (s_d^2) value close to zero, and they placed in a stable region which is defined as moderately compatible to all environments. Thus, the aforementioned genotypes were defined as the most stable hybrids according to the Eberhart and Russel (1966) assessment. In addition, the candidate genotypes 2015-31, 2015-88, 2015-21, 2015-15, 2015-89, 2015-79, 2015-3, 2015-25, 2015-18, 2015-26 and 2015-14, which had the highest grain yield were considered adopted to favorable environmental conditions. The results also revealed that Baharcin, one of the standard varieties, adapted well to the favorable environments, while Antcin and SH9201 poorly adapted to all environments, and Elacin poorly adapted to poor environments (Figure 1).

The stability parameters of the genotypes tested in 2017 were given in Table 7 and the adaptation classes were shown in Figure 2. The mean values of 33 candidate genotypes were higher than the mean value of the experiment. The confidence interval calculated with a 5% probability for grain yield per hectare ranged between 5.54 and 5.72 t ha^{-1}. The mean grain yields of 2016-41, 2016-25, 2016-6, 2016-24, 2016-20 2016-49, 2016-16, 2016-17, 2016-38, 2016-42 and 2016-12 candidate genotypes were considered higher than the mean value of the experiment with a 5% probability. The 2016-22, 2016-28, 2016-102 and 2016-107 popcorn genotypes had a b and R^2 values close to 1.0 and the (s_d^2) value close to zero, and they placed in a stable region which is defined as moderately compatible to all environments. Thus, the aforementioned genotypes were defined as the most stable hybrids according to the assessment of Eberhart and Russel (1966).

In addition, the candidate genotypes 2016-31, 2016-88, 2016-21, 2016-15, 2016-89, 2016-79, 2016-3, 2016-25, 2016-18 and 2016-26, 2016-14, which had the highest grain yield were considered adopted to favorable environmental conditions. The results also revealed that Baharcin, one of the standard varieties, adapted well to the favorable environments, while Antcin and SH9201 poorly adapted to all environments, and Elacin poorly adapted to poor environments (Figure 2).

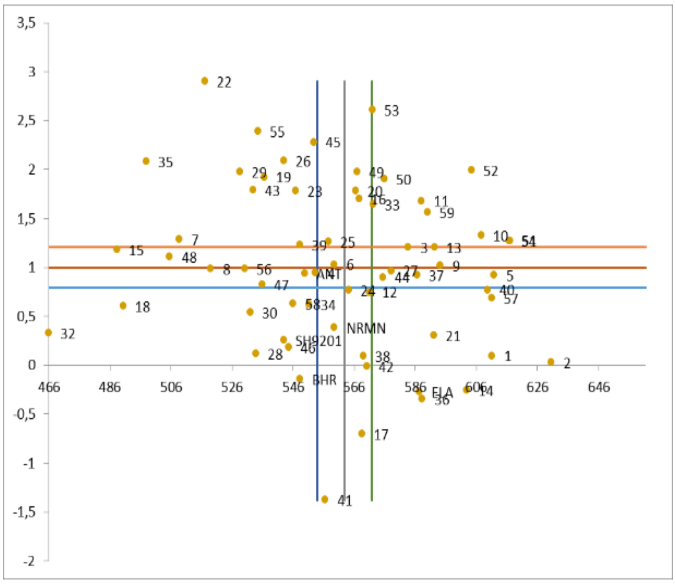

Figure 2. Scattered diagram for grain yields of popcorn hybrids in four different locations in 2017.

Table 6. The stability parameters for the grain yield (t ha^{-1}) of popcorn hybrids tested in four different locations in 2016.

Genotypes	$\bar{x}$		b	A	CV	R^2	s_d^2
2015-31	6.99	A	4.20	-1613.29	0.42	0.61	7650.58
2015-88	6.55	AB	1.85	-361.44	0.15	0.71	973.51
2015-15	6.41	BC	4.97	-2094.76	0.58	0.54	14381.17
2015-35	6.34	BCD	1.32	-89.84	0.07	0.87	183.93
2015-89	6.34	BCD	4.91	-2077.81	0.33	0.78	4607.88
2015-74	6.18	B-E	1.92	-438.73	0.45	0.22	8834.91
2015-79	6.18	B-E	0.44	375.32	0.48	0.01	9795.05
2015-21	6.18	B-E	5.48	-2405.96	0.43	0.72	8017.96
2015-59	6.12	B-F	-1.63	1507.43	0.75	0.07	23882.85
2015-3	6.08	B-G	5.16	-2238.82	0.10	0.98	407.32
2015-57	6.07	B-H	3.90	-1549.08	0.25	0.79	2701.79
2015-54	5.98	C-I	0.06	564.76	0.02	0.15	14.82
2015-26	5.96	C-J	-2.70	2083.36	0.34	0.50	4967.72
2015-94	5.96	C-L	1.36	-158.25	0.32	0.22	4357.33
2015-91	5.96	C-K	4.41	-1842.68	0.28	0.80	3370.07
2015-51	5.93	C-M	1.25	-104.20	0.24	0.30	2492.64
2015-30	5.90	C-N	6.39	-2940.57	0.08	0.99	308.15
2015-18	5.88	C-O	-1.62	1478.79	0.10	0.80	450.27
2015-14	5.82	D-P	3.60	-1399.57	0.55	0.40	13042.59
2015-25	5.82	D-P	3.44	-1313.13	0.45	0.48	8778.70
Baharcin (st)	5.80	D-P	1.25	-104.92	0.36	0.16	5598.57
2015-66	5.76	E-O	0.42	346.95	0.14	0.13	838.38
2015-69	5.75	E-O	0.83	119.97	0.38	0.07	6205.83
2015-33	5.75	E-O	-2.19	1782.81	0.28	0.49	3389.22
2015-2	5.74	E-R	-0.70	959.06	0.13	0.31	748.97
2015-107	5.64	E-S	-2.49	1930.74	0.11	0.90	480.68
2015-4	5.56	F-T	4.08	-1694.90	0.47	0.55	9357.33
2015-37	5.53	F-U	0.78	121.41	0.87	0.01	32548.34
2015-11	5.53	G-U	-4.10	2813.72	0.15	0.93	904.80
2015-20	5.50	H-V	3.13	-1173.16	0.26	0.70	2820.53
2015-22	5.48	I-V	0.53	256.02	0.31	0.05	4030.38
2015-5	5.47	I-V	2.98	-1095.79	0.36	0.52	5540.93
Nermincin (st)	5.45	I-W	0.47	289.15	0.47	0.02	9502.93
2015-102	5.45	I-W	1.02	-12.13	0.33	0.13	4753.79
2015-28	5.44	I-W	0.64	194.61	0.08	0.49	289.24
2015-29	5.42	W-W	1.79	-441.50	0.25	0.44	2780.94
2015-42	5.41	J-X	-0.78	972.03	0.44	0.05	8445.23
2015-36	5.41	J-Y	0.30	372.97	0.61	0.00	15956.06
2015-90	5.40	L-Y	4.81	-2115.37	0.94	0.29	37735.58
2015-7	5.40	K-Y	-0.37	742.17	0.19	0.06	1548.85
2015-24	5.39	K-X	4.36	-1866.78	0.19	0.89	1522.06
2015-63	5.37	M-Y	-0.42	763.83	0.36	0.02	5526.17
2015-50	5.34	N-Y	-1.92	1592.59	0.61	0.14	15785.49
SH9201 (st)	5.33	M-Y	-2.22	1753.84	0.39	0.34	6490.15
2015-58	5.31	O-Y	-0.28	683.73	0.26	0.02	2978.33
2015-16	5.31	O-Y	0.42	297.06	0.98	0.00	41522.86
2015-13	5.31	P-Y	-2.11	1689.50	0.11	0.85	516.83
2015-34	5.22	Q-Y	-0.78	953.73	0.24	0.14	2530.36
2015-113	5.21	Q-Z	-2.18	1719.42	0.55	0.20	12805.81
2015-10	5.20	R-Z	-0.67	888.06	0.49	0.03	10309.45
2015-8	5.16	S-Z	0.21	402.08	0.32	0.01	4306.48
Elacin (st)	5.12	S-Z	-1.73	1470.66	0.75	0.08	24409.89
2015-27	5.09	S-Z	-0.49	778.84	0.12	0.21	613.48
2015-38	5.01	T-Z	0.04	473.69	0.51	0.00	11106.65
2015-1	4.96	U-a	0.58	175.44	0.58	0.02	14597.50
2015-9	4.94	V-a	1.38	-269.59	0.29	0.26	3710.51
2015-32	4.89	W-a	2.15	-693.44	0.88	0.09	33043.68
2015-17	4.84	X-b	0.23	362.25	0.54	0.00	12664.33
Antcin (st)	4.83	Y-b	0.70	100.62	0.60	0.02	15710.19
2015-19	4.66	Zab	-1.15	1107.97	0.36	0.14	5511.68
2015-23	4.65	Zab	2.57	-952.03	0.53	0.27	12127.28
2015-12	4.41	ab	0.52	152.57	0.26	0.06	2807.29
2015-6	4.29	bc	0.96	-104.23	0.11	0.54	541.51
2015-85	3.79	c	2.74	-1125.20	0.12	0.89	642.08
Confidence Interval	X±14.0		X±0.58				
Mean value of the experiment	5.52						

Table 7. The stability parameters for the grain yield (kg ha^{-1}) of popcorn hybrids tested in four different locations in 2017.

Genotypes	$\bar{x}$		b	a	CV	R^2	s_d^2
2016-31	6.61	A	1.00	99.56	0.21	0.27	14876.6
2016-2	6.30	AB	0.03	612.67	0.10	0.00	3394.8
2016-51	6.17	BC	1.28	-101.38	0.29	0.24	28153.6
2016-54	6.16	BC	1.27	-98.46	0.17	0.47	9955.7
2016-5	6.11	BCD	0.92	92.36	0.06	0.77	1369.8
2016-1	6.11	BCD	0.10	554.92	0.18	0.00	11591.9
2016-57	6.11	BCD	0.69	224.93	0.07	0.60	1691.1
2016-40	6.09	B-E	0.77	174.76	0.11	0.42	4392.5
2016-10	6.07	B-G	1.33	-140.84	0.12	0.67	4629.0
2016-52	6.04	B-H	1.99	-515.83	0.06	0.94	1409.9
2016-14	6.03	C-I	-0.25	743.79	0.30	0.01	31117.6
2016-9	5.94	C-J	1.02	19.66	0.11	0.57	4315.1
2016-13	5.92	C-J	1.21	-88.62	0.15	0.52	7231.9
2016-21	5.92	C-K	0.30	421.41	0.05	0.33	1021.4
2016-59	5.90	C-K	1.57	-291.57	0.05	0.95	724.1
2016-36	5.88	C-K	-0.34	780.04	0.14	0.08	6875.5
2016-11	5.88	C-L	1.68	-357.87	0.06	0.93	1236.6
Elacin (st)	5.87	C-L	-0.27	737.59	0.07	0.19	1707.1
2016-37	5.86	C-L	0.92	67.56	0.10	0.58	3319.7
2016-3	5.83	C-M	1.21	-95.88	0.13	0.56	6104.2
2016-27	5.78	D-N	0.97	33.85	0.11	0.55	4107.7
2016-50	5.75	E-O	1.91	-497.68	0.10	0.86	3307.3
2016-44	5.75	F-O	0.90	66.93	0.05	0.84	830.9
2016-33	5.72	G-O	1.64	-353.00	0.12	0.74	5071.5
2016-53	5.72	G-O	2.61	-898.53	0.06	0.97	1120.4
2016-12	5.71	G-P	0.75	149.69	0.07	0.62	1884.3
2016-42	5.70	H-P	-0.01	574.94	0.17	0.00	9572.7
2016-38	5.69	H-P	0.09	517.22	0.03	0.14	290.2
2016-17	5.68	I-O	-0.70	962.52	0.12	0.35	4854.7
2016-16	5.67	I-O	1.70	-389.01	0.08	0.89	2032.4
2016-49	5.67	I-R	1.98	-544.64	0.19	0.63	12349.8
2016-20	5.66	I-S	1.78	-435.80	0.10	0.83	3525.9
2016-24	5.64	I-T	0.77	132.48	0.19	0.21	11809.5
2016-6	5.62	J-T	1.03	-21.35	0.03	0.94	379.1
Nermincin (st)	5.59	J-U	0.39	340.85	0.12	0.15	4511.6
2016-25	5.57	K-U	1.26	-153.97	0.12	0.62	5228.5
2016-41	5.56	K-U	-1.38	1330.54	0.03	0.97	349.8
2016-4	5.53	L-U	0.94	21.39	0.20	0.26	13414.1
2016-45	5.52	M-U	2.28	-731.59	0.17	0.75	9516.7
2016-34	5.51	M-V	0.62	201.55	0.05	0.73	760.5
Antcin (st)	5.49	M-V	0.94	19.79	0.10	0.59	3354.4
Baharcin (st)	5.48	M-V	-0.14	627.56	0.15	0.01	7233.9
2016-39	5.48	M-V	1.23	-144.23	0.07	0.81	1877.5
2016-23	5.46	M-V	1.78	-456.87	0.18	0.60	11545.3
2016-58	5.46	M-V	0.63	191.74	0.24	0.10	18925.1
2016-46	5.44	O-V	0.18	440.35	0.11	0.04	4233.1
SH9201 (st)	5.43	O-V	0.25	399.63	0.21	0.02	15362.1
2016-26	5.43	O-V	2.09	-632.17	0.18	0.67	11483.2
2016-19	5.36	P-W	1.93	-546.85	0.03	0.99	223.5
2016-47	5.36	Q-W	0.82	71.54	0.18	0.25	11012.5
2016-55	5.34	Q-W	2.39	-810.37	0.06	0.97	1052.7
2016-28	5.33	R-W	0.12	466.87	0.13	0.01	5382.2
2016-43	5.33	S-W	1.79	-475.16	0.12	0.77	5138.5
2016-30	5.32	T-W	0.54	225.33	0.06	0.58	1159.6
2016-56	5.30	U-X	0.98	-23.88	0.16	0.38	8632.3
2016-29	5.28	U-X	1.98	-585.41	0.09	0.88	3002.1
2016-8	5.19	V-Y	0.99	-38.67	0.21	0.26	15286.3
2016-22	5.17	V-Y	2.90	-1115.56	0.08	0.95	2252.5
2016-7	5.08	WXY	1.29	-216.89	0.18	0.46	10770.5
2016-48	5.05	WXY	1.11	-120.38	0.13	0.56	5362.4
2016-35	4.98	XYZ	2.08	-673.38	0.10	0.87	3406.9
2016-18	4.90	YZ	0.61	147.63	0.40	0.04	53489.4
2016-15	4.88	YZ	1.18	-176.45	0.08	0.79	1965.0
2016-32	4.66	Z	0.33	280.66	0.04	0.48	628.2
Confidence Interval	$\bar{x}$±9.0		$\bar{x}$±0.21				
Mean value of the experiment	5.63						

DISCUSSION

Considering the sources of variation genotype and environment, the joint analysis of variance revealed significant differences using the F test for the GY traits, which indicates the existence of variation among the genotypes and among the environments tested (Table 2). Regarding the genotype x environment interaction (GE), GY was significant ($p < 0.01$), which evidenced differences in the behavior of the cultivars due to environmental variations. Therefore, it is necessary to search for measures to reduce the effects of the GE interaction, including studies on the stability and adaptability of different genotypes, seeking to discriminate the responses of each genotype to environmental variations to identify those with broad or specific adaptability and those with predictable behavior (Garbuglio et al., 2007; Silva et al., 2013). Next, as stability and adaptability are useful criteria for recommending cultivars, the assessment of genotype responses to environmental variations must be a compulsory step in breeding programmes. Thus, as the cultivars were grouped according to their regression coefficients (less than, equal to, or greater than 1) and the variance of the regression deviations (either equal or not to zero) (Eberhart and Russell, 1966), cultivars with regression coefficients greater than 1 were those adapted to favourable growth conditions; cultivars with coefficients less than 1 were adapted to unfavourable environmental conditions, and those with coefficients equal to 1 had an average adaptation to all environments. Furthermore, genotypes with variances in regression deviations equal to zero were highly predictable, whereas genotypes with regression deviations greater than zero had less predictable responses (Scapim et al., 2010).

The first year results of the study, in which the yield performances of 64 popcorn genotypes were investigated at different locations, revealed that the genotype 2015-31 was the most productive genotype in Isparta (7.07 t ha^{-1}) and Samsun (7.94 t ha^{-1}). The most productive genotype in Izmir was 2015-74 genotype with a grain yield of 6.60 t ha^{-1}, and the 2015-59 genotype had the highest grain yield in the Cankırı (7.15 t ha^{-1}). The 2015-31 genotype has attracted the attentions with its superior yield performance in all locations. In the second year, the highest yield values in Izmir were obtained by 2016-14 (6.80 t ha^{-1}) and 2016-18 (6.79 t ha^{-1}) genotypes. Similarly, 2016-51 (7.22 t ha^{-1}) in Isparta, 2016-31 (7.70 t ha^{-1}) in Samsun and 2016-41 (6.32 t ha^{-1}) genotypes had the highest grain yield.

The results of experiments conducted in different locations and years revealed that the 2015-31, 2016-31, 2016-51 and 2015-59 genotypes are the promising popcorn candidate genotypes based on the high yield and agricultural characteristics.

The stability analysis for the first year of the study showed that the 2015-22, 2015-28, 2015-102 genotypes are the most stable (high adaptation ability) hybrids in terms of b, R^2 and s_d^2 values and identified as the candidate varieties. The 2015-31, 2015-88, 2015-21, 2015-15, 2015-89, 2015-79, 2015-3, 2015-25, 2015-18, 2015-26 and 2015-14 candidate genotypes, which had high grain yields, well adapted to the favorable environmental conditions. Baharcin, one of the standard varieties, adapted well to the favorable environments, while Antcin and SH9201 poorly adapted to all environments, and Elacin poorly adapted to poor environmental conditions.

In the second year, the genotypes 2016-5, 2016-52, 2016-59 and 2016-6 were identified as the most stable hybrids in terms of b, R^2 and s_d^2 values. The candidate genotypes 2016-31, 2016-88, 2016-21, 2016-15, 2016-89, 2016-79, 2016-3, 2016-25, 2016-18 and 2016-26, 2016-14, which had the highest grain yield were considered adopted to favorable environmental conditions.

In the second year, the genotypes 2016-5, 2016-52, 2016-59 and 2016-6 were identified as the most stable hybrids in terms of b, R^2 and s_d^2 values. The genotypes 2016-31, 2016-51 and 2016-54, which had the highest grain yield were well adapted to favorable environmental conditions. The genotypes 2016-22, 2016-35 and 2016-55 poorly adapted to favorable environmental conditions and the 2016-18, 2016-32, 2016-30, 2016-1 and 2016-21 genotypes poorly adapted to the poor environmental conditions. Elacin, one of the standard varieties, adapted well to the poor environments, while Antcin-98, Baharcin and SH9201 genotypes poorly adapted to poor environments, and Elacin genotype poorly adapted to poor environments.

The mean grain yield of popcorn varieties in Konya conditions was reported as 6.39 t ha^{-1} (Tekkanat and Soylu, 2005), while Erdal et al. (2012) determined the mean grain yield of 4 different locations as 4.60 t ha^{-1}. The grain yield of local popcorn genotypes in Kahramanmaras province of Turkey ranged from 3.70 to 4.99 t ha^{-1} (Idikut et al., 2015). In addition, grain yields of popcorn genotypes were determined by Pena et al. (2012), 1.63-2.36 ton ha-1, Silva et al. (2013), 1.79-3.45 tons ha-1, Leite et al. (2021) reported that it varies between 1.86-2.68 tons ha-1. Sakin et al. (2005) indicated that hybrid corn varieties were adversely affected by improper temperature and weather conditions and the grain yield decreased. The yield differences obtained in this study are similar to those reported in the literature. The yield values of popcorn genotypes differed by the effect of both the differences in genetic characteristics of genotypes and the environmental factors of the locations.

CONCLUSIONS

This study was carried out at 8 different locations in 2016 and 2017 to examine the stability of 128 (118 candidates and 5 standards) popcorn maize hybrid genotypes for grain yield and genotype x environment interactions. As a result of the study, it was determined that the G X E interaction is significant. According to the results of stability analysis based on b, r^2 and S_d^2 values, yields of genotypes vary according to environmental conditions, and some genotypes give high yields in good environments (2015-31, 2016-31, 2016-51, 2015-59, 2016-5, 2016-52)., 2016-59 and 2016-6), some genotypes were determined to give stable yields in all environments (2015-22, 2015-28

2015-102, 2016-25). High yield potentials of 2016-31 , 2016-02 hybrid popcorn maize cultivar candidates; The 2016-25 popcorn maize variety candidate, on the other hand, was registered in 2019 due to its high stability capabilities. It was registered as 2016-31 (ATASAM), 2016-02 (Ozturk 1602), 2016-25 (Erdal 1625) at the VSC (Vegatable Seed Committee) meeting in 2022.

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LITERATURE CITED

Alexander D.E. 1988. Breeding special nutritional and industrial types in Corn and Corn Improvement, ed, GF Sprague and JW Dudley. Pp. 869-879. Madison, WI: American Society of Agronomy.

Dickerson G.W. 2003. Specialty corns, http://aces.nmsu.edu/pubs/_h/h- 232.pdf, (Accessed date 02.5.2017).

Duzgunes, O., T. Kesici, O. Kavuncu and F. Gurbuz. 1987. Research and Experiment Methods (Statistical Methods II). Ankara

Eberhart, S.A. and W.A. Russel. 1966. Stability Parameters for Comparing Varieties. Crop Science. 6: 36-40. http://dx.doi.org/10.2135/cropsci1966.0011183X000600010011x

Erdal, S., E. Ozata, M. Pamukcu, O. Savur, M. Tezel and R. Cengiz. 2012. Additive main effects and multiplicative interactions analysis of yield in popcorn (*Zea mays* everta L.) hybrids. University of Akdeniz Faculty of Agriculture Journal. 25(2): 117-121.

Erdal, S., A. Ozturk, M. Pamukcu, E. Ozata and M.C. Sezer. 2018. Public Popcorn Breeding Studies of Turkey. Ekin Journal of Crop Breeding and Genetics. 4(2): 1-7.

Idikut, L., G. Zulkadir, C. Yururdurmaz and M. Colkesen. 2015. The Investigation of Agricultural Characteristics for Local Popcorn Genotypes in Kahramanmaras Conditions. KSU Natural Sciences Bulletin. 18(3): 1-8.

Leite, J.T., A.T.D. Amaral Junior, S.H. Kamphorst, V.J.D. Lima, D.R.D. Santos Junior, K.F.M. Schmitt, Y.P.D. Souza, T.D.O. Santos, R.B. Bispo, G.S. Mafra, E. Campostrini, and W.P. Rodrigues. 2021. Water Use Efficiency in Popcorn (Zea mays L. var. everta): Which Physiological Traits Would Be Useful for Breeding. Plants. 10, 1450. https://doi.org/10.3390/plants10071450.

Little, T. M. and F.J. Hills. 1978. Agricultural experimentation design and analysis.

Nascimento, M., L.A. Peternelli, C.D. Cruz, A.C.C. Nascimento, R.D.P. Ferreira, L.L. Bhering and C.C. Salgado. 2013. Artificial neural networks for adaptability and stability evaluation in alfalfa genotypes. Crop Breeding and Applied Biotechnology. 13: 152-156.

Nguyen, V., L. Cooper, J. Melenson, T.J. Angelopoulus, J.M. Rippe and K. Reimers. 2012. Popcorn is more satiating than potato chips in normal-weight adults. Nutrition Journal. 11: 1-6.

Oz, A. and H. Kapar. 2011. Determination of grain yield, some yield and quality traits of promising hybrid popcorn genotypes. Turkish Journal of Field Crops. 16(2): 233-238.

Ozkan A. 2007. The effect of different nitrogen application doses on agricultural properties and some quality characteristics of two popcorn corn (*Zea mays everta sturt.*) cultivars in Cukurova conditions. C.U Institute of Science. Ph.D. Thesis.

Ozkaynak, E. and B. Samanci. 2003. Comparing the Yield and Yield Properties of popcorn (*Zea mays everta Sturt.*) lines and Selected Hybrids. Akdeniz University Journal of Agricultural Faculty. 16(1): 35-42.

Pajić, Z. 2007. Breeding of maize types with specific traits at the Maize Research Institute, Zemun Polje. Genetika. 39(2): 169-180.

Pena GF, A.D. Amaral Junior, L.S.A. Goncalves, L.S. Candido, C. Vittorazzi, R.M. Riberio and S.P. Freitas Junior. 2012. Stability and adaptability of popcorn genotypes in the State of Rio de Janeiro. Brazil. Genetic and Molecular Research. 11(3): 3042-3050.

Sakin, M.A., S. Gokmen, S. Belen, A. Yildirim and N. Kandemir. 2005. Effects of Cultivar Type on Yield and Quality of Popcorn (*Zea mays everta*). New Zealand Journal of Crop and Horticultural Science. 33: 17-23.

Scapim, C. A., C.A.P. Pacheco, A.T. Do Amaral Júnior, R.A. Vieira, R.J.B. Pinto and T.V. Conrado. 2010. Correlations between the stability and adaptability statistics of popcorn cultivars. Euphytica. 174(2): 209-218.

Silva, T.C.R., A.T. Amaral Junior, L.S.A. Gonçalves, L.S. Candido, C. Vittorazzi and C.A. Scapim. 2013. Agronomic performance of popcorn genotypes in Northern and Northwestern Rio de Janeiro State. Acta Scientiarum Agronomy. 35: 57-63.

Tekkanat, A. and S. Soylu. 2005. Determination of Grain Yield and Important Quality Properties of Popcorn Varieties. S.U. Journal of Faculty of Agriculture. 19(37): 51-60.

Ulger, A.C. 1998. The Effect of Different Nitrogen Doses and Intra row Spacings on Grain Yield and Some Agricultural Properties of Popcorn (*Zea mays everta Sturt.*). Journal of Cukurova University Faculty of Agriculture. 13 (1): 155-164.