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DETERMINATION OF GRAIN YIELD, SOME YIELD AND QUALITY TRAITS OF PROMISING HYBRID POPCORN GENOTYPES

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ABSTRACT

The popcorn (*Zea mays everta Sturt*) is consumed for snack food and its market has been continuously growing in Turkey. Therefore the breeding of new cultivars adapted to local target environments should be started. The experiments were conducted according to Complete Block Design in Samsun province in Turket. Grain yield, tasseling time, plant height, grain moisture at harvest, percentage of unpopped kernels and popping volume were determined for 18 new hybrid genotypes and 4 commercial popcorn cultivars in 2006, 2007 and 2008 years. Significant variations were found for all the traits of genotypes. Based on the means, the grain yields of genotypes ranged from 3535 to 5399 kg ha^{-1}, and popping volume varied from 38.2 to 46.5 cm^{3} g^{-1}. The results indicated that, high yielding, TCM-05-01, TCM-05-02, TCM-05-03, TCM-05-04, TCM-05-05, TCM-05-06, TCM-05-09, TCM-05-10, and TCM-05-12 genotypes with high yielding were selected for yield trial in multiple environments.

Key Words: Breeding; Hybrid popcorn; Quality; Grain yield

INTRODUCTION

Maize is one of the important cereals grown in the world. Popcorn (*Zea mays everta* Sturt.) industry has been increasing continuously throughout the world. Development of microwave technology for popping corn has increased popcorn production. The cultivation of popcorn in Turkey has increased significantly recent years but production is not enough for demand. Turkey imports popcorn as a result of insufficient production and the use of open-pollinated cultivars with low quality by growers. Popcorn has long been a favorite snack food for consumers and its popularity has increased over time in Turkey. Grain yield and popping volume are very important agronomic traits in popcorn. Popcorn kernels are small the proportion of soft starch in relation to hard starch is much smaller than that of flint maize. Maize has been successfully grown over a wide range of environmental conditions. Popcorn growth requirements are similar to those for dent corn, with less adaptability to environmental extremes (Ziegler, 2001). Broccoli and Burak (2004) expressed that the different cultivars of popcorn shown different performance. Well-adapted hybrid cultivars should be breed instead of open-pollinated cultivars for high yield. Hybrid popcorn breeding is similar to those for breeding other corn types. Progress in improvement of popcorn agronomic traits has been slower than in dent corn, so in addition agronomic traits, popcorn breeders must also consider quality traits, such as popping expansion, freedom from hulls and objectionable flavors, and tenderness of the flakes (Ziegler, 2001). Popcorn yield is less than dent corn yield on per unit area. Environmental factors affect yield and yield-related components of corn. In addition, Gözübenli and Konuşkan (2010) expressed that popcorn grain yield and yield-related traits were significantly affected by cultural practices such as nitrogen doses and plant density. They reported the highest popcorn yield obtained at 180 kg N ha^{-1} and 88000 ha^{-1} plants for popcorn grown as a second crop in Turkey.

Popping properties were mostly affected by physical properties of the popcorn kernels. Kernel type, moisture level, kernel size and popping method are effective on popcorn quality parameters. Allred-Coyle et al. (2000) state that popping volume depends on many factors such as size, 1000 kernel weight, moisture contents, test weight, genotype, flake size. Soylu and Tekkanat (2007) determined some quality traits of 12 commercial popcorn varieties and expressed that statistically significant variation were found for all the variables examined. Expansion volume and percentage of unpopped kernels of popcorn genotypes ranged from 18.50 cm^{3}g^{-1} to 35.25 cm^{3} g^{-1} and from 2.42% to 9.90 respectively. Sakin et al. (2005) studied that effect of cultivar type on yield and quality of popcorn. The mean yields of single cross hybrids were 4.45 and 3.30 t ha^{-1} in the first year and second year respectively in their study. Genotype x year interaction for yield and popping volume was significant. According to this study, double cross and synthetic cultivars were suggested for unstable soil and weather condition. Gökmen (2004) found out that hybrid cultivars produced higher expansion volumes than an open pollinated variety. Özkaynak and Samancı (2003) studied on popcorn inbred lines and their testcrosses and expressed that high yielding popcorn hybrids were obtained high yielding inbred lines.

Maximum popping potential of a hybrid can be achieved only if it reaches full maturity. Grain moisture is one of the important traits for popping. Percentage of popped kernel and popping volume are highest at 14.0% moisture (Ademiluyi and Mepba, 2009). Gökmen (2004) investigated the effect of moisture content and popping methods on popping quality of five popcorn genotypes. The highest popping quality was obtained from grains with a moisture content of 14% in this study. Genotype x moisture content interaction was significant for investigated traits. Ertaş et al. (2009) expressed that the optimum moisture content for the highest expansion volume changed between 12 and 14% for different cultivars. They further observed that kernel type, moisture level, kernel size, and popping method were effective on popcorn quality parameters.

The aim of this research was to determine new popcorn hybrid/hybrids with high yield and quality to release.

MATERIALS AND METHODS

The study was an advanced stage of hybrid popcorn breeding program conducted in Black Sea Research Institute in Samsun/Turkey. Combining ability of inbred lines was determined in the previous years. The inbred lines of popcorn with high combining ability were crossed in 2004. These crosses were tested and selected in pre-yield trial in 2005. Selected 18 single crosses and commercial cultivars Koçkompozit, Koççin, Antcin-98, and Nermincin were used as the plant material in the study. While cultivars Koçkompozit and Koççin are composite cultivars, Antcin-98 and Nermincin are single cross hybrids.

The study was conducted in Black Sea Agricultural Research Institute (Samsun-Turkey) experimental field, (Lat. 41°23'N Long. 36°50' E, and 4 m above sea level) in the central of Black Sea Region of Turkey. These hybrids were tested to determine grain yield and some agronomic and quality traits in growing seasons of 3 years (2006,2007, 2008. The experimental design was a randomized complete block with four (2006 year) and three (2007 and 2008 years) replications. The experimental plots included 4 rows, each 5 meters long with spacing 0.7 m between rows and 0.2 m within rows. Fertilizer of 200 kg N, and 70 kg P_2O_5 ha^{-1} was applied (Özkan, 2007). The soil in the location was clay and rich for K. Therefore K fertilizer wasn’t applied to plots. Half of the N was used, when the height of plants were 50-60 cm.

According to State Meteorology Department, the mean of growing period, precipitation was 413.8 mm; temperature was 18.34 ºC in long-term period (1974-2007). The distribution of precipitation was uneven in trial years (Table 1).

Table 1. Climatic data of Samsun (Monthly temperature and precipitation in growing period)

Months	Temperature (ºC)				Total Rainfall (mm)			
	1974-2007	2006	2007	2008	1974-2007	2006	2007	2008
April	11.1	11.1	9.7	13.5	58.3	30.7	28.0	46.2
May	15.3	14.4	17.2	15.1	50.6	58.0	43.2	34.1
June	20.0	20.8	22.1	20.0	47.9	37.7	32.8	59.4
July	23.1	22.0	23.8	23.2	31.3	16.4	13.9	10.3
August	23.2	24.9	24.4	24.4	50.9	0.2	146.6	4.0
September	19.8	19.7	20.3	20.1	87.4	150.2	89.3	122.0
October	15.9	16.9	17.0	16.4	87.4	138.1	77.2	76.5
Mean	18.34	18.54	19.21	18.96	-	-	-	-
Total	128.4	129.8	134.5	132.7	413.8	431.3	432.0	352.0

Data on grain yield, days to tasseling, height of plant, grain moisture rate (content) in harvest, percentage of unpopped kernel and popping volume were measured for genotypes. Data were taken on tasseling time (days from planting to tasseling of 50 % of plants), grain yield (kg ha^{-1}), plant height (cm), grain moisture in harvest (%), were estimated from a sample of all plants in two rows of every plot. Grain yield was corrected for a standard humidity of 14.5 and was transformed into kg ha^{-1} (Arnhold et al., 2009). After harvest, for each replication, genotypes samples were dried by natural convection at room temperature to 14% moisture. Popping tests were performed by using a hot air popping machine (Arçelik, ARK77 MP, 230 V, 1200W). The moisture content of samples was 14±0.5% before popping. Before and after popping, the number of kernels for each sample was counted. Popped samples were poured into a 2000 mL plastic graduated cylinder, and volume recorded (Troyer, 2001; Ceylan and Karababa, 2004; Gökmen, 2004; Sakin et al., 2005; Soylu and Tekkanat, 2007).

Expansion volume = [Total popped volume (cm^3)] / [Original sample weight (g)]

Percentage of unpopped kernel=(Number of total unpopped kernels/Original number of kernels) X 100

All the data were analyzed with according to ANOVA procedures using the Statistical Software Package. The comparison of the treatment means was made by the Duncan’s multiple range test ((Little and Hills, 1978)).

RESULTS AND DISCUSSION

The statistical analysis of investigated characters of popcorn genotypes were given in Table 2. Genotype and G X E were significant for all characters studied. Year (E) was significant for grain yield, tasseling time and grain moisture. Block was significant for all characters except plant height and percentage of unpopped kernel.

Table 2. Summary of ANOVA for variables examined in popcorn genotypes

Source of Variation	DF	Mean squares					
		Grain Yield	Tasseling Time	Plant Height	Grain moisture	Percentage of unpopped kernel	Popping volume
Year (E)	2	22140126 **	1148.00*	274.50 ns	532.33**	140.01 ns	0.77
Block (Env)	3	2091532 **	16.14*	538.98 ns	2.71**	0.79 ns	0.21**
Genotype (G)	21	2171318 **	442.21**	26032.20**	5.10**	949.14**	1.28**
G X E	42	730430 *	127.30*	17018.09**	2.76**	64.40**	0.50**
Error	151	426997	2.04	104.70	0.63	0.23	0.09
CV (%)		14.93	1.99	4.61	3.85	7.90	2.34

**, *: indicates significance at 0.01 and at 0.05 respectively. CV: Coefficient of Variation

Grain Yield

Eighteen genotypes were selected among 30 single cross hybrid genotypes in pre-yield trial. The differences of grain yield of the popcorn genotypes were statistically significant in 2006, 2007 and 2008 (Table 3). The effect of years on grain yield and genotype x year interaction for grain yield was significant. Based on the means, the grain yields of genotypes ranged from 3535 to 5399 kg ha^{-1}, and averaged 4376 kg ha^{-1}. The highest grain yield was obtained from promising hybrids TCM-05-05, TCM-05-03, TCM-05-06, TCM-05-10, cultivars Nermincin and Koçcin. Based on the means, yields of genotypes TCM-05-05, TCM-05-03, and TCM-05-06 had higher than commercial cultivars Antcin-98 and Koçkompozit. The mean yields of genotypes in 2006 were higher than the yields in 2007 and 2008.

Table 3. Mean data and statistical groups of popcorn genotypes

Genotypes	Grain yield (kg ha^{-1})				Tasseling time (day)			
	1.year	2.year	3.year	Mean	1.year	2.year	3.year	Mean
TCM-05-01	4807 cg**	3487 bf**	5019 ab*	4525 bf**	72.3 fi**	66.7 df**	73.0ef**	70.6 i**
TCM-05-02	4248 fi	3449 bf	5354 a	4432 bf	74.3 ae	68.3 be	74.7 ac	72.4 cf
TCM-05-03	6268 a	4340 ab	4723 ad	5226 a	73.8 bf	67.3 cf	73.7 ce	71.6 ei
TCM-05-04	5181 be	3449 bf	4698 ad	4525 bf	72.0 gi	68.3 be	73.7 ce	71.3 fi
TCM-05-05	6231 a	5086 a	4603 ae	5399 a	72.3 fi	66.3 ef	73.7 ce	70.8 hi
TCM-05-06	5775 ab	4234 ac	4597 ae	4960 ab	72.3 fi	66.0 ef	73.7 ce	70.6 i
TCM-05-07	5537 ad	3505 bf	3648 df	4324 cg	72.5 fi	69.3 ae	72.3 f	71.4 fi
TCM-05-08	5060 bf	3976 bd	3770 df	4351 cg	75.5 a	71.3 ac	74.3 bd	73.7 ab
TCM-05-09	4066 gi	3700 bf	4593 ae	4201 fh	73.5 cg	69.0 ae	73.3 df	71.9 eh
TCM-05-10	5339 ae	3893 be	4968 ac	4815 ae	73.8 bf	67.3 cf	73.7 ce	71.6 ei
TCM-05-11	4552 eh	3244 dg	4252 bf	4098 fi	68.8 j	64.0 f	70.3 g	67.7 j
TCM-05-12	4909 bg	3887 be	4133 bf	4392 bf	74.5 ad	68.7 be	73.7 ce	72.3 dg
TCM-05-13	3669 hi	2474 g	4217 bf	3535 i	75.3 ab	70.7 ad	75.7 a	73.9 a
TCM-05-14	4774 cg	3821 be	3187 f	4009 fi	75.0 ac	70.7 ad	75.3 ab	73.6 ac
TCM-05-15	4976 bg	3487 bf	4262 bf	4324 dg	72.8 eh	66.7 df	73.7 ce	71.0 gi
TCM-05-16	4890 bg	3554 bf	3571 ef	4087 fi	73.8 bf	69.0 ae	75.3 ab	72.7 be
TCM-05-17	4228 fi	3068 eg	3850 cf	3797 gi	74.5 ad	71.7 ab	74.3 bd	73.5 ad
TCM-05-18	3575 i	2823 fg	4419 ae	3688 hi	75.8 a	73.0 a	73.3 df	74.0 a
Koçkompozit	4680 dg	3179 dg	4375 ae	4137 fh	73.3 dh	69.0 ae	74.0 ce	72.1 eg
Antcin-98	4790 cg	3337 cg	4347 ae	4221 eh	71.0 i	67.3 cf	73.7 ce	70.7 i
Nermincin	5612 ac	4186 ac	4656 ae	4898 ac	71.8 hi	67.0 df	73.7 ce	70.8 hi
Koçcin	5119 bf	4185 ac	4934 ac	4783 ad	73.3 dh	67.3 cf	73.3 df	71.3 fi
Mean	4922 A**	3653 B	4372 C	4376	73.3 A**	68.4 B	73.7 A	72.0
CV (%)	13.35	14.98	15.24	14.93	1.31	3.12	0.93	1.99

Means followed by the same letter in the same column are not significantly different.

Grain yield was effected genetic and environmental conditions. Different genotypes have different yield and agronomic performance in different environments (Ziegler, 2001). Özkaynak and Samancı (2003) reported that the yields of nine single cross popcorn hybrids ranged from 2720 kg ha^{-1} to 4640 kg ha^{-1} in Turkey. Gökmen et al. (2001) found that the grain yield of an open-pollinated popcorn cultivar varied between 3855 kg ha^{-1} and 4970 kg ha^{-1}, in different N doses, as average two years. Sakin et al. (2005) reported that the mean yields of single cross hybrids were obtained 4.45 and

3.30 t/ha in the first year and second year respectively. It is well-known that hybrid cultivars should be grown instead of open pollinated cultivars under optimum environmental conditions.

Tasseling Time

Days to tasseling are given Table 3. The differences of tasseling period of the genotypes were statistically significant for in every year and as average. Genotype x year interaction for tasseling time was also significant.

That tasseling period of genotypes was longer in the first and third years than in the second year was attributed that higher temperature was measured in May, June and July in the second year (Table 1). Based on the means, tasseling period of popcorn genotypes varied among 67.7 - 74.0 days. The hybrids TCM-05-18, TCM-05-13, TCM-05-08, TCM-05-14, and TCM-05-17 had the latest tasseling time. The hybrid TCM-05-11 had the earliest tasseling period. Other high yielding genotypes TCM-05-03 and TCM-05-05 flowered in 71.6 and 70.8 days respectively.

Agronomic traits are the parameters to select a genotype for a target location. Tasseling period is an important yield-related character in popcorn. High yielding and early maturing hybrids are generally preferred in maize cultivation. Early flowered genotypes commonly mature early. Some corn cultivars is early because it is more vigorous and grows faster. Earlier-flowering corn plants have smaller plant size and longer kernel-filling periods (Troyer 2001). Gökmen et al (2001) reported that there was a significant difference in the days up to tasseling period of popcorn with various nitrogen rates and plant densities. The tasseling period became shorter with the increased nitrogen level and low sowing density. Our results are higher than dent and popcorns studied in the same experiment area (Öz and Kapar, 2003; Öz and Kapar, 2010).

Plant Height

Plant height of the genotypes varied from 190 to 241 cm in 2006, from 195 to 250 cm in 2007 and from 188 to 245 cm in 2008 (Table 4). There were statistically significant differences among genotypes in every year and as average. Year effect for plant height was not significant. Genotype x year interaction for plant height was significant. Based on the means, the promising genotypes TCM-05-02, TCM-05-03, TCM-05-06, TCM-05-10 and standard commercial cultivars Koçkompozit and Antcin-98 have the highest plant height.

High plant height is desired in maize cultivation. Plant height is a genetic character and it is also affected by plant density and environmental condition. Higher plant densities produced taller plant (Gözübenli and Konuşkan, 2010). The later flowering and the taller plant height are due to longer day length and not due to temperature effects (Troyer 2001). These results are similar to the results of other popcorn studies conducted in the same location (Öz and Kapar, 2010).

Grain Moisture

The results of Duncan’s multiple range tests are summarized in Table 3. There were statistically significant (P<0.01) differences among the genotypes with respect to grain moisture. Genotype x year interaction for grain moisture was significant. Grain moisture ranged from 19.7 to 22.1%, and the promising cultivar TCM-05-18, commercial cultivars Koçkompozit, Nermincin and Koçcin had the highest grain moisture (22.1%, 21.8%, 21.6% and 21.4% respectively) in the harvest. Based on the means, the genotypes had lower grain moisture in the second year than first and third years. The reason for this, the genotypes could be matured earlier in the second year than first and third years.

Moisture content is one of the primary measures of popping characteristic and affected to harvest index. Damaged kernels don’t pop properly. Moisture of corn ear at harvest should be 18-20%, also, 16-18% for shelled corn (Mason and Waldren, 1978). Expansion volume was affected from kernel moisture at popping. Popcorn kernels from different varieties and different sizes require different optimum grain moisture content for maximum expansion volume (Allred-Coyle et al. 2000; Tian et al. 2001; Gökmen 2004; Ertaş et al. 2009). Song and Eckhoff (1994) also reported that the optimum grain moisture content was different for different-sized kernels. Smaller kernels required slightly higher moisture to achieve the maximum expansion. Maturity is also important for popping potential, and maximum popping potential of a popcorn hybrid can be achieved only if it reaches full maturity.

Percentage of unpopped kernels

Mean data of genotypes and the results of Duncan’s multiple range test are given in Table 4. There were statistically significant (P<0.01) differences among the genotypes with respect to popping volume for in three years and as average. The means of unpopped kernels were 6.72% in 2006, 6.57% in 2007, and 4.86% in 2008. Based on the means, TCM-05-05 and TCM-05-06 genotypes had the lowest percentage (2.8%), cultivar Koçkompozit had the highest (10.1%) percentage of unpopped kernels. The reason for the highest percentage of unpopped kernels of cultivar Koçkompozit than other genotypes could be higher heterogeneity in kernel sizes (Song et al., 1991; Sakin et al., 2005).

Percentage of unpopped kernels is one of the most important quality characters. Song et al (1991) reported that popcorn genotypes and kernel sizes significantly affect the percentage of unpopped kernels. Genotypic differences of cultivars significantly affected expansion volume, percentage of unpopped kernels, kernel size, protein content, test weight and 1000 seed weight in the open pollinated varieties (Soylu and Tekkanat, 2007). The percentage of unpopped kernels is profoundly affected by environmental factors as well as by genotype (Sakin et al., 2005).

Popping Volume

There were statistically significant (P<0.01) differences among the genotypes with respect to popping volume for in three years conducted study and as average. The means of popping volume were obtained 42.0 $cm^3 g^{-1}$ in every year and as average. Based on the means, the hybrid TCM-05-06 and the commercial cultivar Koçkompozit had the lowest, new hybrid TCM-05-13 had the highest popping volume. The new hybrids TCM-05-07, TCM-05-16, TCM-05-08, and

Table 4. Mean data and statistical groups of popcorn genotypes

Genotypes	Plant height (cm)				Grain moisture (%)			
	1.year	2.year	3.year	Mean	1.year	2.year	3.year	Mean
TCM-05-01	208 fg**	198 gh**	242 a**	216 eg**	19.5 l**	17.5 ef**	22.1 c**	19.7 i**
TCM-05-02	233 ac	230 bd	233 ad	232 ac	20.2 jk	17.5 ef	23.1 bc	20.3 ei
TCM-05-03	238 ab	250 a	230 ae	240 a	20.4 ij	17.5 ef	22.6 bc	20.2 fi
TCM-05-04	219 df	213 eg	225 af	219 dg	22.2 bc	18.2 b	22.1 c	21.0 cf
TCM-05-05	234 ac	240 ac	210 ef	229 bd	21.9 d	17.6 df	22.3 bc	20.8 cg
TCM-05-06	235 ac	243 ab	225 af	235 ab	20.5 hi	16.9 gh	23.4 ac	20.3 ei
TCM-05-07	228 be	230 bd	215 cf	225 ce	20.9 fg	17.6 df	22.4 bc	20.4 ei
TCM-05-08	200 gh	203 gh	217 cf	207 hi	19.7 l	17.2 g	23.0 bc	19.9 hi
TCM-05-09	225 ce	230 bd	215 cf	224 ce	20.7 gh	15.7 i	22.8 bc	19.9 hi
TCM-05-10	229 be	233 bd	230 ae	231 ac	20.1 k	16.8 h	23.0 bc	19.9 hi
TCM-05-11	224 ce	223 df	235 ac	228 bd	22.0 k	18.0 b	22.1 c	20.9 cf
TCM-05-12	226 be	243 ab	213 df	228 bd	20.0 k	17.4 f	22.5 bc	20.0 gi
TCM-05-13	224 ce	213 eg	205 fg	214 fh	20.1 k	17.5 ef	23.5 ac	20.4 ei
TCM-05-14	226 be	227 ce	220 bf	225 ce	19.7 l	17.6 df	22.2 c	19.8 hi
TCM-05-15	230 ad	213 eg	232 ad	226 cd	19.7 l	17.7 df	21.9 c	19.8 hi
TCM-05-16	190 h	208 fh	188 g	196 j	20.6 hi	17.1 g	26.0 a	21.2 bd
TCM-05-17	196 gh	202 gh	208 fg	202 ij	21.0 f	16.9 gh	25.1 ab	21.1 ce
TCM-05-18	201 gh	195 h	235 ac	211gi	23.5 a	17.9 bc	24.5 ac	22.1 a
Koçkompozit	241 a	230 bd	242 a	238 a	23.6 a	18.9 a	22.4 bc	21.8 ab
Antcin-98	218 ef	232 bd	245 a	232 ac	21.4 e	17.6 df	22.5 bc	20.6 dh
Nermincin	224 ce	210 fh	240 ab	225 ce	22.4 b	17.7 cd	24.1 ac	21.6 ac
Koçcin	225 ce	220 df	218 cf	221 be	21.8 d	17.9 bc	24.4 ac	21.4 ac
Mean	221 (ns)	222	224	222	21.0 B**	17.5 C	23.1 A	20.5
CV (%)	3.75	4.28	5.57	4.60	0.77	0.79	6.32	3.85

Means followed by the same letter in the same column are not significantly different.

Table 5. Mean data and statistical groups of popcorn genotypes

Genotypes	Percentage of unpopped kernels (%)				Popping volume (cm^3/g)			
	1. year	2. year	3. year	Mean	1. year	2. year	3. year	Mean
TCM-05-01	5.5 gh**	3.8 i**	4.6 gh**	4.6 i**	43.6 be**	42.0 c**	41.9 c**	42.6 ef**
TCM-05-02	11.7 a	9.7 d	7.1 cd	9.5 b	41.0 fh	46.1 a	45.6 a	44.0 bd
TCM-05-03	7.4 e	2.3 k	2.2 k	4.0 j	39.4 hi	40.3 e	40.1 ef	40.0 hj
TCM-05-04	5.4 gh	7.5 f	3.7 i	5.6 h	41.1 fh	41.3 d	41.3 cd	41.2 gh
TCM-05-05	3.9 jk	1.3 l	3.2 j	2.8 k	44.4 ad	41.8 cd	41.3 cd	42.7 df
TCM-05-06	3.5 j	2.8 jk	2.3 k	2.8 k	39.2 hi	37.3 h	37.8 h	38.2 k
TCM-05-07	4.9 hi	3.1 j	1.1 m	3.1 k	44.2 ae	46.0 a	45.6 a	45.3 ab
TCM-05-08	6.5 f	2.8 jk	1.7 l	3.7 j	45.5 ab	44.1 b	44.3 b	44.7 ac
TCM-05-09	8.9 c	7.2 f	5.1 fg	7.1 de	42.1 eg	44.3 b	44.4 b	43.4 ce
TCM-05-10	6.0 fg	9.8 d	2.0 kl	5.9 h	41.0 fh	39.8 ef	39.8 fg	40.3 hi
TCM-05-11	4.3 ij	8.3 e	6.5 de	6.4 h	39.3 hi	44.1 b	44.1 b	42.2 eg
TCM-05-12	5.4 gh	12.2 a	4.3 h	7.3 d	43.1 cf	41.2 d	41.4 cd	42.0 fg
TCM-05-13	7.5 e	3.7 i	2.9 j	4.7 i	46.0 a	45.4 a	45.5 a	45.6 a
TCM-05-14	8.7 c	5.0 h	6.8 de	6.8 ef	45.1 ac	44.2 b	43.9 b	44.5 ac
TCM-05-15	7.8 e	7.7 f	7.7 b	7.7 c	42.5 dg	44.3 b	44.1 b	43.5 ce
TCM-05-16	5.0 h	6.5 g	5.6 f	5.7 h	44.3 ae	45.8 a	45.7 a	45.2 ab
TCM-05-17	4.3 ij	11.1 c	4.4 h	6.6 fg	41.2 fh	39.5 f	39.6 fg	40.2 hj
TCM-05-18	7.9 de	4.5 h	7.6 bc	6.7 eg	38.4 i	39.1 fg	39.1 g	38.8 jk
Koçkompozit	10.4 b	11.9 ab	8.1 b	10.1 a	38.6 i	37.5 h	39.3 fg	38.5 k
Antcin-98	6.7 f	11.5 bc	10.6 a	9.6 b	44.0 ae	41.7 cd	40.8 de	42.4 eg
Nermincin	8.6 cd	8.5 e	6.4 e	7.8 c	40.7 gi	39.7 ef	39.0 g	39.9 hj
Koçcin	7.6 e	3.8 i	3.2 j	4.9 i	39.1 hi	38.6 g	39.2 fg	39.0 ik
Mean	6.72 A**	6.57 A	4.86 B	6.12	42.0 (ns)	42.0	42.0	42.0
CV (%)	7.41	5.37	6.65	7.90	3.36	0.97	1.18	2.34

Means followed by the same letter in the same column are not significantly different.

TCM-05-14 had higher popping volume than those of other hybrids and the commercial cultivars.

Popping volume is the most important trait because the commercial buyer buys by weight but sells the popped popcorn by volume (Mason and Waldren, 1978). Different kernel sizes and genotypes directly affect the popping volume (Ceylan and Karababa, 2001). The factors affected popping volume are moisture content, popping temperature, kernel size and shape, variety or genotype, kernel density, drying condition, and kernel damage (Song et al., 1991). Song and Eckhoff (1994) reported that when the grain moisture content varies from the optimum value by ±1%, the expansion volume could be reduced by as much as 2%. Expansion volume was affected from kernel moisture at popping. Sakin et al. (2005) reported that there was a positive relationship between grain yield and popping volume ($r=0.86$, $P<0.05$) in the open pollinated popcorn cultivars. They also found that popping volume varied from 16.7 to 46.5 cm^3 g^{-1} in some single, three way and double cross popcorn hybrids. Gökmen (2004) suggested that larger-sized grains produced the greatest flake size and the smallest percentage of unpopped kernels compared with the small-sized and medium-sized kernels. Ertaş et al. (2009) reported moisture content affcted expansion volume and flake size in the conventional method.

CONCLUSIONS

In plant breeding programs, candidate genotypes are usually evaluated in different environments before desirable ones are selected. Breeders try to select highly stable genotypes across environments. In the study, it was possible to investigate and select more productive hybrids with higher yield and greater popping expansion. Good popcorn cultivar must be high yield and quality. The yield, yield-related and quality characters of new single cross popcorn genotypes were investigated. The some single cross hybrids (TCM-05-01, TCM-05-02, TCM-05-03, TCM-05-04, TCM-05-05, TCM-05-06, TCM-05-09, TCM-05-10, and TCM-05-12) had high grain yield and quality traits than those of commercial cultivars. The hybrid popcorn TCM-05-07 was selected for next trials; because of it has low percentage of unpopped kernel and high popping volume. The genotypes were selected for yield trial in different environment.

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