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Effects of cultivar type on yield and quality of popcorn (*Zea mays everta*)

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Abstract Popcorn (*Zea mays everta*) has long been a favourite snack food for consumers and its popularity has increased over time. Quality as well as yield is important in popcorn. The popping volume of popcorn is the most important quality trait. In this study, yield and some quality characteristics of single-cross and three-way cross genotypes and open-pollinated cultivars were compared. In this trial, 21 genotypes were investigated during 1997 and 1998. Seven of them were single crosses, seven were three-way crosses, and seven were open-pollinated cultivars. There were significant differences among genotypes for yield, popping volume, and percentage of unpopped kernels in both years. Cultivar types had similar yields in the first year, when environmental conditions were optimum, whereas hybrid genotypes had lower yield values in the second year because of unfavorable rainfall and temperature. Popping volume was significantly higher in hybrid genotypes than open-pollinated cultivars whereas the percentage of unpopped kernels was c. 50% lower in hybrids. Therefore, well-adapted hybrid cultivars should be grown instead of open-pollinated cultivars under optimum environmental conditions.

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INTRODUCTION

The use of popcorn (*Zea mays everta* Sturt.) as a snack food has been increasing continuously throughout the world. Yield is a very important trait in popcorn as in other corn types. The most important factor affecting yield in popcorn is genotype (Pajic 1990; Pajic & Babic 1991). Popcorn cultivars vary from region to region, based on ecological conditions, adaptation ability of the cultivar, and consumers' preferences (Ziegler & Ashman 1994).

Increasing yield per unit area in corn depends upon the extent of the use of hybrid cultivars in production as well as the selection of the best cultivars for specific ecological conditions and the use of high quality seeds (Sencar 1988). The first-generation hybrids obtained from crossing inbred lines provide c. 20–30% higher yields than their parental cultivars (Leonard et al. 1963).

Quality is also important in specialty corns like popcorn. Therefore, improvement of quality traits is generally considered the most important objective in popcorn breeding programmes (Dofing et al. 1990). Popping volume is the most important quality trait in popcorn (Song et al. 1991), because popcorns with high popping volumes are tender and palatable (Dofing et al. 1990). Commercial popcorn sellers buy popcorn by weight and sell it by volume after popping.

Crumbaker et al. (1949) observed that there were significant differences among popcorn inbred lines in terms of transmitting popping ability to their progenies. In addition, Dofing et al. (1990) reported that there were significant differences among hybrid cultivars in popping volume, and that hybrid genotypes provided higher values than open-pollinated cultivars. Long-term mass selection for increasing popping volume decreases the ear diameter and seed yield per ear (Weaver & Thompson 1957). There is usually a negative relationship between the popping

volume and overall seed yield. Higher popping volumes were recorded for low- or medium-yielding cultivars whereas high-yielding cultivars had lower popping volumes (Pajic 1990). Consumers desire good popping popcorn with low numbers of unpopped kernels, and tender, palatable, delicious flakes having less seed coat remaining. On the other hand, growers look for high yielding capacity, plant stability, and good resistance to diseases and pests (Babic & Pajic 1992).

Popcorn consumption has continuously increased in Turkey as well as in many other countries. However, Turkey imports considerable amounts of popcorn as a result of insufficient production and the use of open-pollinated cultivars with low quality by growers. In addition, research on hybrid popcorn is very limited. The aim of this study was to compare the yield and some quality characteristics of hybrid cultivars to open-pollinated cultivars.

MATERIALS AND METHODS

The study was conducted in the research fields of the Research Institute of Rural Services in Tokat, Turkey in 1997 and 1998. Long-term average precipitation for this region was 153.9 mm/year. The amounts of total precipitation in the vegetation periods of 1997 (186.7 mm/year) and 1998 (167 mm/year) were higher than the long-term average but there were irregularities among the monthly distributions. Because long-term dry periods spanned 4–5 months, plants were irrigated three times in both years. The average temperatures of the growing seasons were 17.9 and 19.1°C, respectively.

Soils of the research area had a texture classification of loam. The soils were slightly alkaline, medium in lime content, and very low in salt content. The soils were low in available phosphorus (P) but rich in potassium (K). Thus, 60 kg/ha P_2O_5 and 150 kg/ha nitrogen (N) were applied. Overall, 21 cultivars were used in the trial. Genotypes were selected based on a previous study run in 1996 and consisted of 105 single-cross hybrids, 30 three-way cross hybrids, and 15 open-pollinated cultivars. These were the highest yielding and the best popping genotypes of each cultivar type of the 1996 study (Gokmen unpubl. data). All of the three-way cross genotypes, as well as OKUR E 169, OKUR E 234, and OKUR 370 single-cross cultivars, were obtained from a private breeding company, OKUR Zirai Ltd (Adana, Turkey). The single-cross cultivar POP 608 was from Purdue University, United States, whereas the rest of the single-cross cultivars were from Antalya Agricultural Research Institute, Turkey. The kernel type of all but two genotypes was classified as "yellow pearl".

The experiment was arranged in a randomised complete block design with three replications. Seeds were sown in the first week of May in four-row plots, 5 m long, with 70 cm between rows. Plant spacing within the rows was 20 cm. Seeds were hand-planted and 2–3 seeds were put in each hill. Extra seedlings were thinned when plants reached 15 cm in height. Ears were harvested by hand, dried and threshed. Later, seeds were naturally dried at room temperature to c. 14% moisture, and yield was calculated. Popping tests in the study were performed using a hot air popping machine (Arcelik brand, model ARK77 MP, 230 V, 1200W). Popping was conducted using two 75 ± 0.5 g samples having 14 ± 0.5% moisture from each plot. If the difference between two samples was higher than 5%, then a third sample was popped to reduce variation. Total kernel numbers were determined in each sample before popping. Before popping the main samples, a test sample was popped for heating up the machine to standardise the operation. At the end of popping, the popped corn was gently poured into a 2000 ml beaker which was then inverted once, and the volume was recorded. Unpopped kernels were counted and recorded. Popping volume and percentages of unpopped kernels were calculated according to Dofing et al. (1990) by using the formula below:

Popping volume = total popped volume (ml)/original sample weight (g)

Percentage of unpopped kernels = (number of unpopped kernels/total number of kernels) × 100

Analysis of variance was done using the MSTAT computer program and significance level was determined by *F* test. Means were compared based on Duncan's multiple comparison test (Little & Hills 1978).

RESULTS AND DISCUSSION

Yield

Grain yields of the genotypes varied from 2.39 to 5.99 t/ha in 1997 and from 2.64 to 4.66 t/ha in 1998 (Table 1). There were significant differences among cultivars in both years. Based on the means, the white-kernel 'Antalya' population was the best with 5.14 t/ha yield. It was followed by the yellow-kernel open-pollinated cultivars 'Aydin' and Ankara

University Agricultural Faculty (A.U.Z.F.), the single-cross hybrid OKUR E 234, the open-pollinated Cukurova University Agricultural Faculty (C.U.Z.F.), and the three-way cross hybrid OKUR TRD 3. The lowest yield was obtained from the red-kernel population A.U.Z.F with 2.23 t/ha. The highest yielding cultivars also had the largest kernels.

Yields of genotypes in the first year were higher than those in the second year (Table 1). Yields of the genotypes were lower in 1998, by between 4% (P.203 × 85ANT2503) and 43% (OKUR TRD 110). There was less rain, irregular rain distribution, and higher temperatures in 1998 than in 1997. This yield decrease in 1998 was more noticeable in hybrid cultivars that have lower adaptation ability.

Mean yields of single-cross hybrids, three-way cross hybrids, and open-pollinated cultivars in the first year were not significant. Yield differences between cultivar types were pronounced and significant in the second year. Open-pollinated cultivars which contain many genetically different genotypes, have higher yield stability than do hybrid genotypes (Hallauer et al. 1988). On the other hand, hybrid cultivars have high environment × genotype interactions; therefore, seed yield may decrease considerably in unfavorable environments (Gokmen 1997).

In contrast to dent and flint corns, yields of the popcorn hybrids were lower than those of the open-pollinated cultivars in this study. This situation could be explained by the fact that selection in popcorn is primarily done for quality (Weaver & Thompson 1954), and ecological conditions were not appropriate for hybrid genotypes in the region where the research was conducted (Gokmen 1997). Nevertheless, income per unit area is high in hybrid popcorn even if yield is low. This is because popcorn from hybrids is 1.5–2 times more expensive than that from open-pollinated cultivars in Turkey.

Table 1 Yield of popcorn (*Zea mays everta*) cultivars (t/ha). Different letters in the same column indicate significant difference ($\alpha = 0.01$). (A.U.Z.F., Ankara University Agricultural Faculty; C.U.Z.F., Cukurova University Agricultural Faculty.)

Genotypes	1997	1998
Single-cross		
OKUR E 169	5.18 ab	3.16 ef
OKUR E 234	5.52 a	3.86 bcd
OKUR E 370	4.51 ab	3.45 cde
P.203 × 85ANT2503	3.34 bc	3.20 ef
85ANT2503 × 85ANT2509	4.08 abc	3.07 ef
P.206 × 85ANT2503	4.22 abc	3.26 def
POP 608	4.28 abc	3.07 ef
Three-way cross		
OKUR TRD 3	5.38 a	3.16 ef
OKUR TRD 8	4.72 ab	3.43 cde
OKUR TRD 12	4.20 abc	3.28 def
OKUR TRD 86	4.05 abc	3.51 cde
OKUR TRD 110	4.69 ab	2.68 f
OKUR TRD 128	4.78 ab	3.36 cde
OKUR TRD 201	4.81 ab	3.07 ef
Open-pollinated		
Antalya (white)	5.99 a	4.30 ab
Antalya (yellow)	3.29 bc	2.64 f
C.U.Z.F.	5.40 a	3.95 bc
A.U.Z.F. (red)	2.39 c	2.07 g
A.U.Z.F. (yellow)	4.91 ab	4.66 a
Aydin	5.87 a	4.20 ab
Tasova	4.53 ab	3.19 ef
Mean		
Single-cross	4.45	3.30 b
Three-way cross	4.66	3.21 b
Open-pollinated	4.63	3.57 a
Years	4.58	3.36

Year × genotype interaction was also significant for yield. In the second year, yields of all genotypes decreased but not to the same degree; therefore, rankings of the genotypes for yield changed. For example, the OKUR E 169, OKUR E 234, OKUR TRD 3, OKUR TRD 8, OKUR TRD 128, OKUR TRD 201 hybrid cultivars and the 'Tasova' population were in the first group in 1997 but not in the second year.

Popping volume

High popping volume is as important as yield in popcorn. Popping volumes varied from 17.3 to 46.5 cm^3/g in 1997 and from 16.7 to 46.0 cm^3/g in 1998. Differences among genotypes were significant (Table 2). The lowest value was obtained for the red-kernel population from A.U.Z.F. in both years, whereas the highest values were obtained from different hybrid genotypes. Single-cross hybrids and three-way cross hybrids varied significantly for popping volume. For example, among hybrids, the single-cross OKUR E 234 and the three-way cross OKUR TRD 110 were in the last group, whereas the P608, P203 × 85ANT2503, and OKUR TRD 3 hybrids were in the first group for popping volume (Table 2). Park et al. (2000) noted that physical characteristics of popcorn hybrids vary from hybrid to hybrid. Crumbaker et al. (1949) reported that inbred popcorn lines had significant differences in combining ability for the trait.

The biggest differences among the means of single-cross hybrids, three-way cross hybrids, and open-pollinated cultivars were for quality characteristics. The mean popping volumes of single-cross

Table 2 Popping volume of popcorn (*Zea mays everta*) cultivars (cm^3/g). Different letters in the same column indicate significant difference ($\alpha = 0.01$). (A.U.Z.F., Ankara University Agricultural Faculty; C.U.Z.F., Cukurova University Agricultural Faculty.)

Genotypes	1997	1998
Single-cross		
OKUR E 169	38.8 cd	45.3 ab
OKUR E 234	34.7 de	38.0 c
OKUR E 370	38.7 cd	38.7 bc
P.203 × 85ANT2503	46.5 a	38.7 bc
85ANT2503 × 85ANT2509	38.2 cd	41.0 abc
P.206 × 85ANT2503	39.3 cd	37.0 c
POP 608	45.0 ab	40.0 abc
Three-way cross		
OKUR TRD 3	45.0 ab	41.7 abc
OKUR TRD 8	41.7 bc	35.7 c
OKUR TRD 12	36.0 de	46.0 a
OKUR TRD 86	41.3 bc	40.9 abc
OKUR TRD 110	35.0 de	37.3 c
OKUR TRD 128	38.3 cd	39.2 bc
OKUR TRD 201	37.5 cde	38.5 c
Open-pollinated		
Antalya (white)	36.7 cde	39.3 bc
Antalya (yellow)	19.0 g	24.0 d
C.U.Z.F.	25.3 f	25.7 d
A.U.Z.F. (red)	17.3 g	16.7 e
A.U.Z.F. (yellow)	32.7 e	29.3 d
Aydin	27.7 f	27.1 d
Tasova	27.5 f	25.7 d
Mean		
Single-cross	40.2 a	39.8 a
Three-way cross	39.3 a	39.9 a
Open-pollinated	26.6 b	26.8 b
Years	35.3	35.5

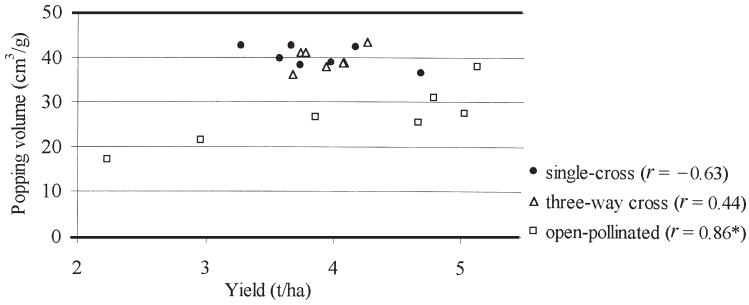

Fig. 1 Distribution of single-cross, three-way cross, and open-pollinated popcorn (*Zea mays everta*) cultivars as to yield and popping volume. Each point represents the mean of 2 years.

and three-way cross hybrids were c. 35% higher than that of open-pollinated cultivars in both years. Other researchers also have reported higher popping volumes for hybrids than for open-pollinated cultivars (Dofing et al. 1990; Belen 1999). This may be a result of the heterogeneity in grain sizes and higher rates of softer endosperm in grains of open-pollinated cultivars (Song et al. 1991).

There was a positive relationship between yield and popping volume ($r = 0.86$, $P < 0.05$) in open-pollinated cultivars (Fig. 1). This can probably be explained by the fact that the larger-sized kernels produced the greatest flake size and the smallest percentage of unpopped kernels compared with the small-sized and medium-sized kernels (Song et al. 1991; Gokmen 2004).

Genotype × year interaction for popping volume was also significant. Popping volumes of OKUR E 169, OKUR E 234, 85ANT2503 × 85ANT2509, OKUR TRD 12, and 'Antalya' (yellow) genotypes increased in the second year whereas volumes of P.203 × 85ANT2503, POP 608, and OKUR TRD 86 genotypes decreased. On the other hand, popping volumes of OKUR E 370, OKUR TRD 86, C.U.Z.F., A.U.Z.F. (red), and 'Aydin' genotypes were similar in both years (Table 2). Differences in popping volumes of genotypes in different years could be a result of diverse effects of environmental factors on grain endosperm starch properties (Babic & Pajic 1992).

Percentage of unpopped kernels

One of the most important quality characters in popcorn is the percentage of unpopped kernels. Significant differences for this character among genotypes were seen in both years (Table 3). The percentages of unpopped kernels of open-pollinated cultivars were higher than those of hybrids. Means were 4.3% in single-cross hybrids, 4.4% in three-way cross hybrids, and 9.6% in open-pollinated cultivars in 1997, whereas they were 2.1%, 2.2%, and 5.7%, respectively, in 1998. Based on multiple comparison tests, single-cross hybrids and three-way cross hybrids were usually in the same group (Table 3). The reason for higher percentages of unpopped kernels in open-pollinated cultivars than in hybrids could be higher heterogeneity in kernel sizes (Song & Eckhoff 1994).

A high negative correlation ($r = –0.88$, $P < 0.01$) between yield and percentage of unpopped kernels was observed in open-pollinated cultivars (Fig. 2). In popcorn, when grains are larger, yields are higher (Pajic 1990), but percentage of unpopped kernels is proportionally lower (Song et al. 1991). Lower yielding open-pollinated cultivars usually have smaller grains, and thus a higher percentage of unpopped kernels.

The significant difference between years in the percentage of unpopped kernels indicates that this character is profoundly affected by environmental factors as well as by genotype. Genotype × year interaction was also significant.

CONCLUSION

Cultivar types had similar yields in the first year, when environmental conditions were optimum, whereas hybrid genotypes had lower yield values in the second year because of unfavorable rainfall and temperature. This could be a result of poorer adaptation ability of hybrids to stress. Therefore, in regions where soil and weather conditions are not very suitable for popcorn culture or in regions where environmental conditions are unstable, double-cross hybrids or synthetic cultivars should be grown, because their adaptability is greater than that of single-cross and three-way cross hybrids.

Popping volume, which is the most important quality character, was significantly higher in hybrid

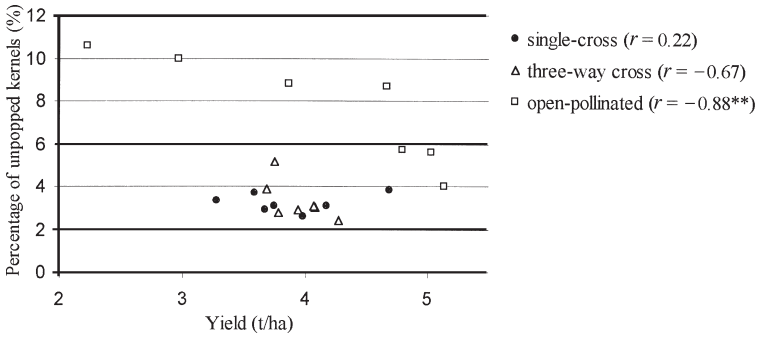

Fig. 2 Distribution of single-cross, three-way cross, and open-pollinated popcorn (*Zea mays everta*) cultivars as to yield and percentage of unpopped kernels. Each point represents the mean of 2 years.

Table 3 Percentage of unpopped kernels of popcorn (*Zea mays everta*) cultivars (%). Different letters in the same column indicate significant difference (α = 0.01). (A.U.Z.F., Ankara University Agricultural Faculty; C.U.Z.F., Cukurova University Agricultural Faculty.)

Genotypes	1997	1998
Single-cross		
OKUR E 169	3.9 fg	2.3 efgh
OKUR E 234	5.2 efg	2.4 efgh
OKUR E 370	3.3 g	1.9 fgh
P.203 × 85ANT2503	5.0 efg	1.5 fgh
85ANT2503 × 85ANT2509	5.1 efg	2.2 fgh
P.206 × 85ANT2503	3.3 g	2.9 defgh
POP 608	4.5 efg	1.2 h
Three-way cross		
OKUR TRD 3	3.4 g	1.4 gh
OKUR TRD 8	3.8 fg	2.3 efgh
OKUR TRD 12	6.3 def	4.2 de
OKUR TRD 86	3.7 fg	1.9 fgh
OKUR TRD 110	5.9 defg	1.8 fgh
OKUR TRD 128	4.1 fg	2.0 fgh
OKUR TRD 201	3.7 fg	2.0 fgh
Open-pollinated		
Antalya (white)	4.7 efg	3.3 defg
Antalya (yellow)	13.7 a	6.3 bc
C.U.Z.F.	9.4 bc	7.9 ab
A.U.Z.F. (red)	12.9 a	8.3 a
A.U.Z.F. (yellow)	8.1 cd	3.4 def
Aydin	7.0 de	4.3 d
Tasova	11.5 ab	6.1 c
Mean		
Single-cross	4.3 b	2.1 b
Three-way cross	4.4 b	2.2 b
Open-pollinated	9.6 a	5.7 a
Years	6.1	3.3

cultivars than in open-pollinated cultivars, whereas the percentage of unpopped kernels was c. 50% lower in hybrid cultivars. Therefore, well-adapted hybrid cultivars should be grown instead of open-pollinated cultivars under optimum environmental conditions, because quality is as important as yield in popcorn.

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