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Analysis of the pre-registration maize breeding trials and the germplasm developed in Altınova breeding station from 2015 to 2018

Analiza predkomisijskih pokusa kukuruza i germplazme razvijene u oplemenjivačkoj stanici u Altınovi od 2015. do 2018. godine

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ABSTRACT

Main goal of the most breeding programs is to develop highly adaptive hybrids in various environments, and the most important limitation are complex interactions between genotype, environment and management. Every hybrid breeding program follows certain strategy for new hybrid development. One possible strategy is to develop hybrids with lower adaptability, achieving best performance in "high input" environments (breeding for "race-horses"). However, another approach is to breed for hybrids with higher adaptability and stable performance across a wide range of environments (breeding for "work-horses"). High stability needs to be accompanied by high yield performance to insure profits, so stability should be monitored along with performance in breeding trials. Aim of this research was to analyze the new germplasm developments and their performances in the pre-registration trials in Turkey by the means of BLUP and GGE models. Heritability estimates for grain yield ranged from 0.58 to 0.85, and relative stability of all hybrids and checks is detected across all years. Cause of the high estimates of G×L interaction were crossovers of genotype performances across locations. The location Altinova was the least stable location across years. One hybrid was selected as a future check based on stability parameters across environments. As G×E interaction remains the greatest challenge in modern maize breeding, more research is needed in this field. Therefore mixed-model based approach is a valuable tool for analysis of genotype performances in maize breeding trials.

Keywords: breeding, G×E interaction, germplasm, maize

SAŽETAK

Glavni cilj komercijalnih oplemenjivačkih programa na kukuruzu je razviti hibride visoke prilagodljivosti u raznim okolinama, pri čemu glavno ograničenje predstavljaju kompleksne interakcije između genotipa, okoline i upravljanja. Svaki oplemenjivački program slijedi određenu strategiju za stvaranje hibrida. Jedna od strategija je stvaranje hibrida koji nemaju vrhunsku adaptabilnost, ali mogu postići najviše prinose u visokoprinosnim okolinama („trkaći konji"), dok je druga strategija stvaranje hibrida visoke adaptabilnosti u raznim okolinama („radni konji"). Visoka stabilnost mora biti popraćena visokim prinosima kako bi se osugurao profit, stoga bi se u oplemenjivačkim pokusima stabilnost trebala pratiti zajedno s prinosom. Cilj ovoga istraživanja je analiza nove germplazme (inbred linija i hibrida) kroz predkomisijske pokuse na raznim lokacijama u Turskoj, korištenjem BLUP i GGE metoda za predviđanje, odnosno stabilnost prinosa. Heritabilnost za prinos zrna iznosila je od 0.58 do 0.85, a relativna stabilnost svih hibrida i standarda je zabilježena u svim godinama. Uzrok visokih vrijednosti G×L interakcije su različite vrijednosti genotipova kroz lokacije. Lokacija Altınova bila je najmanje stabilna kroz sve četiri godine. Jedan hybrid je izabran kao budući standard na osnovu stabilnosti u svim okolinama. Kako G×E interakcija i dalje predstavlja najveći izazov u modernom oplemenjivanju kukuruza, potrebno je još istraživanja u tome području, a korištenje mješovitih modela predstavlja vrijedan alat za analizu genotipova u oplemenjivačkim pokusima.

Ključne riječi: oplemenjivanje, G×E interakcija, germplazma, kukuruz

INTRODUCTION

Hybrid maize breeding requires considerable efforts and funds due to the highly developed markets worldwide and state-of-the-art technological applications in breeding programs. Main goal of most of the breeding programs is grain yield, which shows positive linear relationship to the year of hybrid development (Duvick, 2005). Main limits to the development of the highly adaptive hybrids are the genotype × environment (G×E) and more complex genotype × environment × management (G×E×M) interactions (Tollenaar and Lee, 2002). G×E and G×E×M interactions appear to be the number one factor in keeping maize breeder's jobs secure (Bernardo, 2016) and prediction of hybrid performances uncertain. One of the objectives of maize breeding is to maximize genetic gain per unit of time and cost and one of the main strategies in efficient utilization of available resources by bridging the G×E and G×E×M interactions is defining the target population of environments (TPE) representative of the area and management targeted for hybrid production (Messina et al., 2011). Once the TPE has been defined, the careful characterization of the agro-meteorological scenarios needs to be performed (Bustos-Korts et al., 2018; Tardieu et al., 2018) to allow the dissection of interactions. Efficiency of breeding is limited by several factors, one of the main being trait heritability. Modelling of the trait variance to estimate heritability is conveniently done by the restricted maximum likelihood (REML) based mixed modelling approach, allowing to estimate the unbiased variance components (Piepho et al., 2008; Van Eeuwijk et al., 2016), comprising the simplest form of best linear unbiased predictions of genotypic variance (BLUP). Every hybrid breeding program follows certain strategy of new hybrid development. One possible strategy is to develop the hybrids with low adaptability, achieving best performance in "high input" environments, while breeding for performance in "low input" environments is neglected (breeding for "race-horses"). However, another approach is to breed for hybrids with high adaptability and stable performance across a wide range of environments (breeding for "work-horses"; Tollenaar and Lee, 2002). High stability needs to be accompanied by high yield performance to insure profits, so stability should be monitored along with performance in breeding trials (Piepho et al., 2008). Aim of this research was to analyze the new germplasm developments and their performances in the pre-registration trials by the means of BLUP and GGE models.

MATERIALS AND METHODS

Trials were set with 15 to 16 experimental hybrids at four locations in Turkey from 2015 to 2018. These hybrids were selected based on the two year results of hybrid performance testing (first year of screening trials, and second year of testing on several locations).Trial locations were Altınova, Manisa and Adana in all four years while location Mersin was discarded in 2017 and 2018 due to the severe weather conditions that affected the trial quality. Five to six best performing commercial checks were chosen each year according to the sales data obtained from the Tarım Kredi Kooperatifleri database

(DKC 6589, DKC 6590, DKC 6630, Helen, LG 30692, Kermes, Kalumet, P 31 G98, P 1921, P 2088, Albayrak). In 2015 on all locations total number of hybrids was 16 with 16 checks, in 2018 in Altınova and Manisa total number of hybrids was 16 with five checks, while in other years and locations total number of hybrids was 15 with 5 checks. Trials were set with four-row plots as a completely randomized design in four replicates. Each plot (five meters long, with standard inter-row spacing of 0.7 meters) represents one hybrid. Planting was performed from the late March up to the first decade of May, and harvest was performed manually in September. Grain yield was estimated by weighing all ears from two middle rows. Cob weight and grain moisture were determined from five-ear sample for each plot. Parental lines of experimental hybrids developed by Agricultural Institute Osijek (AIO) were genotyped with maize SNP50 array (Ganal et al., 2011) as a part of the continuous AIO genotyping efforts (Jambrović et al., 2008, 2014). Trial data analysis was performed in R programming environment (R Core Team, 2018) in two steps. First, a restricted maximum likelihood (REML) based mixed model was set with lme4 library on single year basis (Bates et al., 2014) as $y_{ij}=\mu+\mathbf{G}_i+\mathbf{GL}_{ij}+\mathbf{r}_{ij}+region$, with random terms in bold and *i(i=1...n)* being the i-th genotype assessed in *j(j=1...n)* locations. Random intercept with fixed mean was assumed and variance-covariance structure was treated as unstructured. Locations Altınova and Manisa were treated as "WESTERN" region, while Adana and Mersin were considered "EASTERN" region. Heritability was calculated from variance components based on entry-mean approach (Hallauer et al., 2010) as: $h^2 = \sigma_G^2 / (\sigma_G^2 + (\sigma_{GL}^2 / nL) + \sigma_e^2 / nLnR)$ where σ_G^2 is genotypic variance, σ_{GL}^2 is genotype-location interaction, σ_e^2 is pooled error, and *nL* i *nR* are numbers of locations and replicates. Best linear unbiased predictions (BLUP) of hybrid performances were added to the fixed intercept. The BLUPs for location means within years were also calculated. Second part of the analysis was focused on hybrid performance stability. To analyze stability, genotype plus genotype-by-environment (GGE) models were set using R *gge* library (Laffont et al., 2013).

RESULTS AND DISCUSSION

Heritability estimates were 0.58 in 2015, 0.65 in 2016, 0.85 in 2017 and 0.82 in 2018. Considerably lower heritabilities were detected in years 2015 and 2016 compared to 2017 and 2018. Cause of the lower obtained heritabilities were the high estimates of G×L interaction (not shown). Cause of the high estimates of G×L interaction were crossovers of genotype performances across locations. The location Altinova was the least stable location across years. The instability of this experimental location is visible in BLUP estimates of the environmental effects (Figure 1) and high loading values in separate directions from other locations (except Manisa in 2015) in 2015 and 2016 in the GGE models (Figure 2A and B).

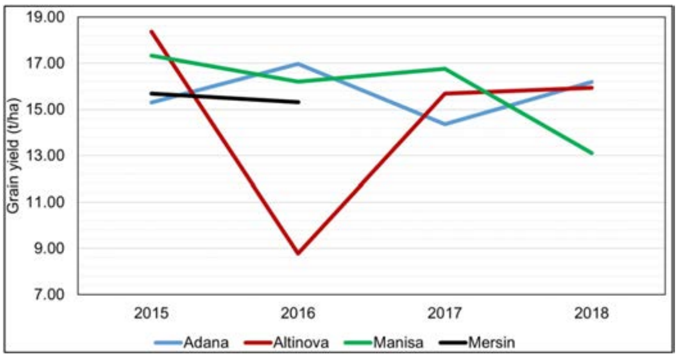

Figure 1. BLUP estimates of the location effects in pre-registration breeding trials from 2015–2018

Relatively stable performances of all experimental hybrids and checks were detected in the GGE analysis during all four years examined. Directions of the environmental effects indicated the dissimilarity of interaction effects in Altınova and Manisa compared to other two experimental locations in year 2015 and dissimilarity of interactions in Altinova compared to other three locations in 2016 (Figure 2A and B). In years 2017 and 2018, most hybrids displayed high adaptability to the selected environments, while performances and interactions of several hybrids were defined by specific environments. Hybrids with high adaptability can be considered "work-horses", while the best performing hybrids in only certain environments can be considered "race-horses" (Tollenaar and Lee, 2002). High stability in performance needs to be accompanied by the high

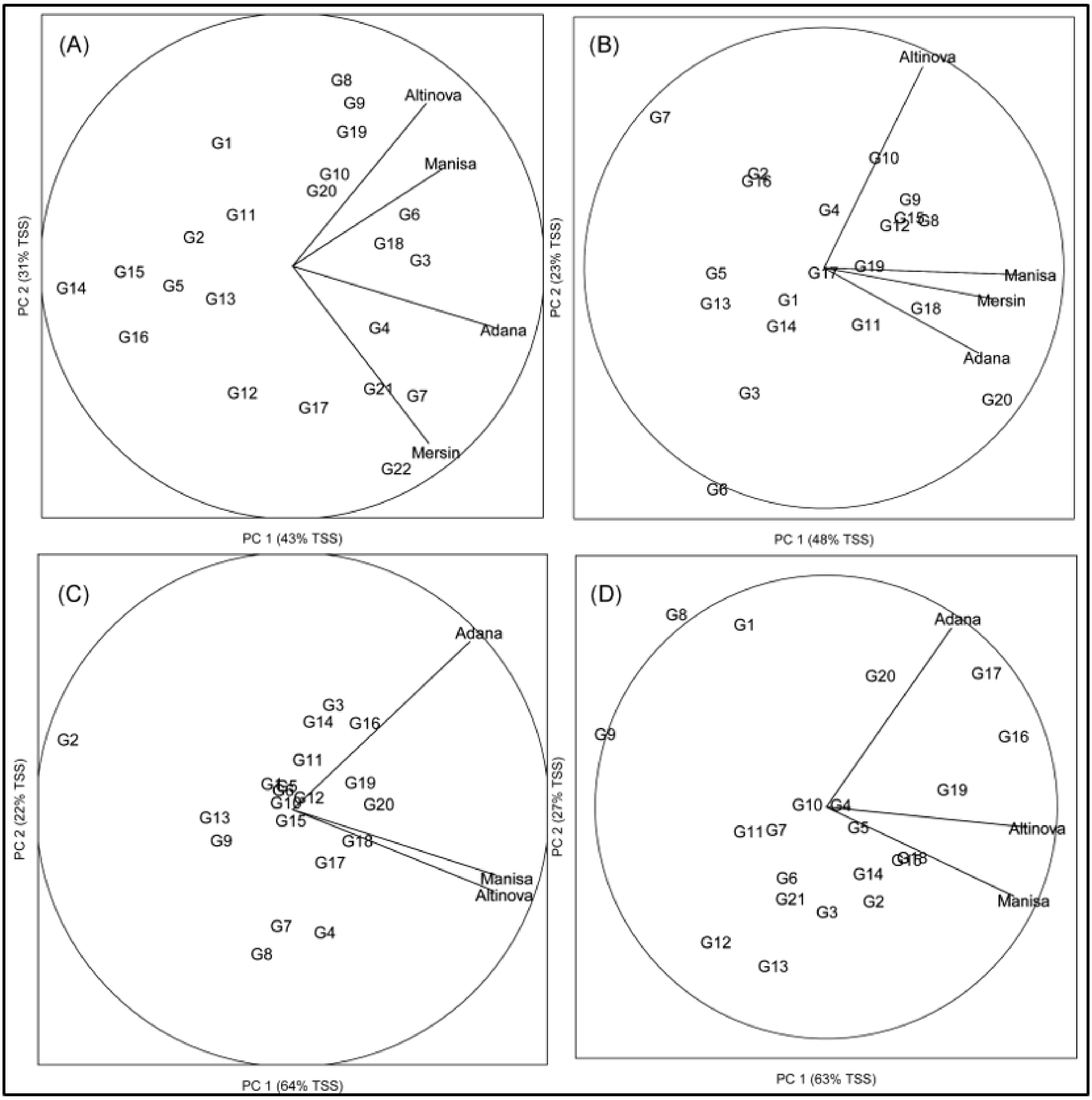

Figure 2. Biplots of the results of GGE analysis for grain yield stability in pre-registration breeding trials in 2015 (A), 2016 (B), 2017 (C) and 2018 (D). Arrows represent eigenvectors of environments

average yield to ensure profits. Inspection of the BLUP values of hybrids revealed the hybrid OS227×OS7798/2 in 2015 (G9 in Figure 2A). Hybrid was selected to enter pre-registration trials based on performance in 2014 in small pre-commission trial set on two locations. Next season the hybrid entered the official registration process, and was registered in 2017 under the name Albayrak. High stability throughout years 2016-2018 (Figure 2B–D, G9 in 2016, G19 in 2017 and 2018) accompanied with high yield performance (Figure 3) show that this is a true high yielding "work-horse" type of hybrid. Commercial checks were G17-G22 in 2015 and G16-G20 from 2016 to 2018. In 2017 and 2018, hybrid Albayrak was treated as internal performance check (genotype 19). As G×E interaction remains the greatest challenge in modern maize breeding, van Eeuwijk et al. (2016) presented statistical framework for dealing with it which includes the mixed-model based approach.

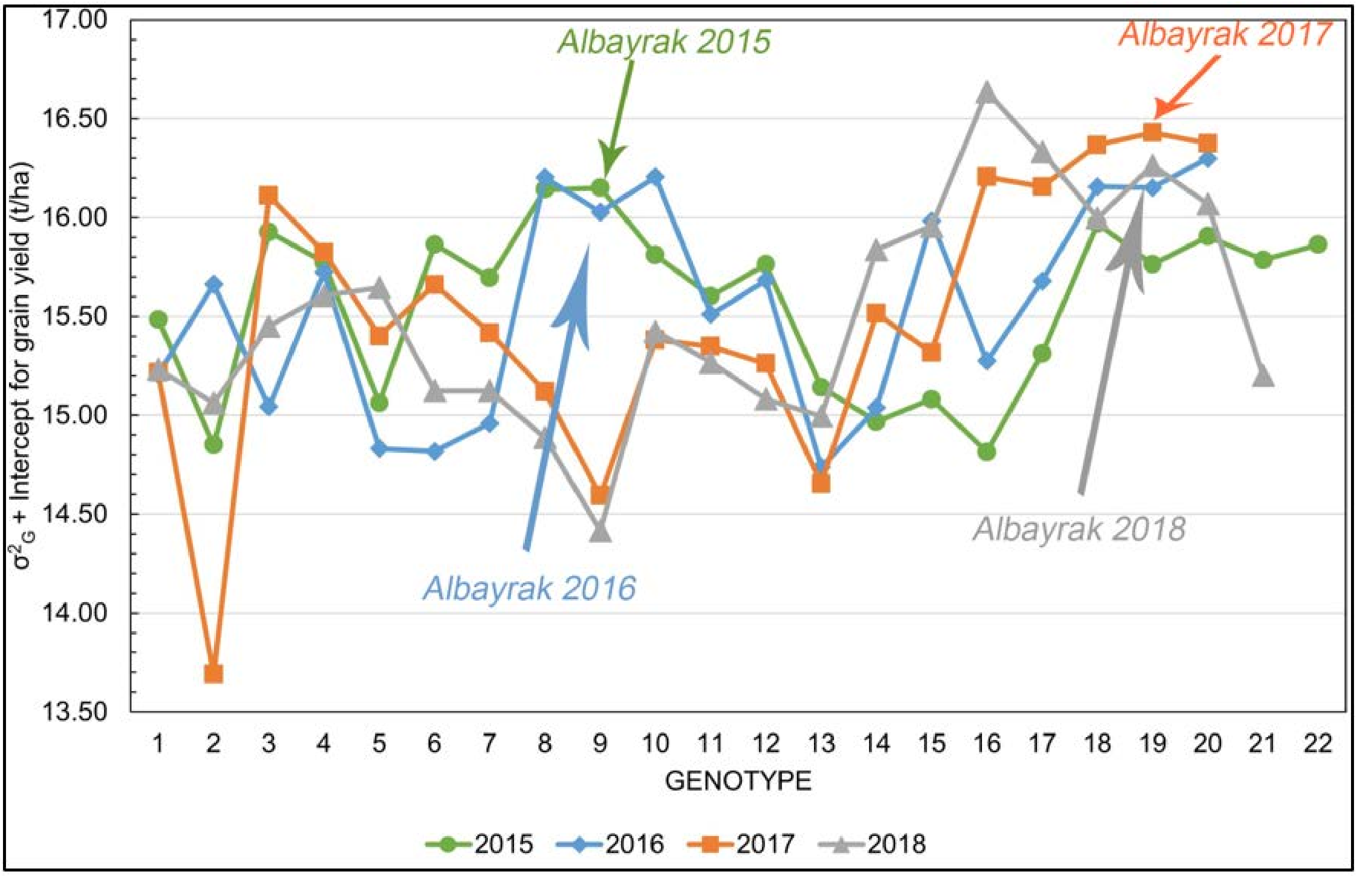

Figure 3. BLUP estimates of grain yield in pre-registration breeding trials from 2015–2018. Hybrid Albayrak is denoted from discovery to commercialization

CONCLUSIONS

Relatively stable performances of all experimental hybrids and checks were detected across all years. Hybrid Albayrak was selected as a commercial check based on both yield and stability performances. Stability analysis and mixed model based approach are recommended for dealing with high yielding environments. As G×E interaction remains the greatest challenge in maize breeding, more research is needed to further explain these complex patterns.

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