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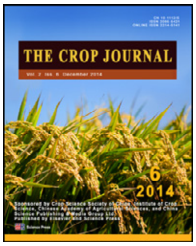

Maize forage aptitude: Combining ability of inbred lines and stability of hybrids

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ABSTRACT

Breeding of forage maize should combine improvement achieved for grain with the specific needs of forage hybrids. Production stability is important when maize is used for silage if the planting area is not in the ideal agronomic environment. The objectives of the present research were: (i) to quantify environmental and genetic and their interaction effects on maize silage traits; (ii) to identify possible heterotic groups for forage aptitude and suggest the formation of potential heterotic patterns, and (iii) to identify suitable inbred line combinations for producing hybrids with forage aptitude. Forty-five hybrids derived from diallelic crosses (without reciprocals) among ten inbred lines of maize were evaluated in this study. Combined ANOVA over environments showed differences between genotypes (G), environments (E), and their interactions (GEI). Heritability (H^2), and genotypic and phenotypic correlations were estimated to evaluate the variation in and relationships between forage traits. Postdictive and predictive AMMI models were fitted to determine the importance of each source of variation, G, E, and GEI, and to select genotypes simultaneously on yield, quality and stability. A predominance of additive effects was found in the evaluated traits. The heterotic pattern Reid-BSSS × Argentine flint was confirmed for ear yield (EY) and harvest index (HI). High and broad genetic variation was found for stover and whole plant traits. Some inbred lines had genes with differential breeding aptitude for ear and stover. Stover and ear yield should be the main breeding objectives in maize forage breeding.

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Abbreviations: Y_{sbtk}, observation of the analyzed variable; μ, general mean; α_s, environments effect; $\beta_b(\alpha_s)$, block b effect nested in environments; γ_t, treatment t effect; $\gamma_t \times \alpha_s$, interaction t treatment × environment s effect; ε_{sbtk}, observation error; GEI, genotype × environment interaction; AMMI, additive main effects and multiplicative interactions; EY, ear yield; HI, harvest index; IPC, interaction principal component; IPCA, interaction principal component analysis; NIRS, near infrared spectroscopy; RMSPD, root mean square predictive difference; SY, stover dry matter yield; WD, whole plant digestibility; WY, whole plant dry matter yield; WDY, digestible whole-plant dry matter yield; GCA, general combining ability; SCA, specific combining ability.

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1. Introduction

Silage maize allows feeding cattle daily throughout the year. It is commonly used as a primary source of energy, is easy to produce and store, and is very well accepted by ruminants. When the whole plant is harvested, ear and stover contribute to the final forage dry matter yield. Therefore, both components must be considered. Since digestibility of plant components varies with genotype, maize quality is determined by plant morphology and architecture.

An important question is which germplasm should be used for breeding programs aimed at forage maize with high digestibility/ingestibility characteristics. Modern inbred lines with the highest digestibility are expected to be the best germplasm [1]. Modern maize germplasm has been developed by centuries of empirical improvement for grain, followed by decades of scientific improvement. For economic and genetic reasons, forage maize improvement should combine breeding for grain with breeding for the specific needs of forage hybrids [1].

Tolenaar et al. [2] pointed out that grain maize selection over time has made it possible to improve stability because modern varieties have higher levels of tolerance to stress and diseases than older ones. In fact, thorough selection among various materials has been applied to improve grain production. However, there is still insufficient information on the environmental and genotype response of other plant components, or on yield or quality.

Modern hybrids have proved to have, on average, 5.5% lower in vivo cell wall digestibility than older ones, resulting in a 2.0% reduction in dry matter digestibility, despite a tendency to a slight but significant increase in grain content [1]. Production stability is an essential property, especially when maize is intended for forage production, because, in general, sowing areas are located in dairy farms near urban centers or other marginal areas that are not ideal agronomic environments for potential yield expression. As a result, low and uneconomic yields may be obtained. For this reason, the selection of forage genotypes should be based on the criteria of genotype × environment interaction (GEI) and stability/adaptability. GEI is a universal phenomenon that arises when different genotypes are evaluated in various environments, as reported in the voluminous literature [3–7]. Strong interaction of this kind complicates the selection of superior genotypes and reduces the correlation between genotypic and phenotypic values [8–10], hindering progress in selection [11–13].

The presence of interaction justifies expanding the number of environments for evaluation or predicting the expected variation among environments [14]. Grain yield shows significant interaction [15]. However, there is no clear information about GEI variance for forage traits. Multivariate techniques are most appropriate for explaining the multidimensional nature of this interaction [16,17]. One such is the additive main effects and multiplicative interaction model (AMMI) [12,18,19]. It is a methodology that combines ANOVA for the evaluation of genotype and environment additive effects with interaction principal component analysis (IPCA). Biplots [20] are graphical representations of interactions that are highly recommended when there is a qualitative interaction [21,22]. Biplots also allow simultaneous graphs of additive effects of genotypes and environments versus GEI and the estimation of stability parameters [23,24]. Gauch and Zobel [18,19] developed a predictive methodology for selecting the best AMMI model.

The success of forage breeding programs depends not only on the amount of genetic variation present in the germplasm but also on the extent to which it is heritable. Knowledge of heritability influences the choice of selection procedures [25]. The estimation of additive and epistatic gene effects is a prerequisite for effective improvement. The existence of a heterotic pattern, "Reid-BSSS × flint", has been demonstrated for ear yield (EY) and harvest index (HI) [26]. However, General Combining Ability (GCA) exceeded Specific Combining Ability (SCA) in flint × dent crosses with respect to qualitative and quantitative forage traits [26,27]. Thus, additive gene action for whole plant dry matter yield was shown when two dent populations were crossed [28]. With respect to maize vegetative components, crosses between divergence heterotic groups reduced SCA effects and increased additive ones [29].

The objectives of the present study were: (i) to quantify the effects of the environmental and genetic variation and their interaction on stover yield, ear yield and digestibility traits that determine forage aptitude; (ii) to identify inbred lines suitable for inclusion in the development of hybrids with forage aptitude and (iii) to differentiate inbred lines based on the response of their derived hybrids to environmental changes.

2. Materials and methods

2.1. Plant material

We selected ten maize inbred lines that represent a wide range of racial origins, maturity, and grain type (Table 1). Forty-five hybrids from diallelic crosses without reciprocals generated by the ten inbred lines and three commercial hybrids (Checks) with outstanding forage aptitude were evaluated: 4-F-37 (Check 1), 369 (Check 2) and SD5 (Check 3).

2.2. Design of the experiment and traits

Thirty ears of each cross were harvested and trials were conducted for two years in sites located in the dairy region

Table 1 – Number, source, Food and Agriculture Organization of the United Nations (FAO) maturity, and grain type of ten inbred lines included in the diallelic crosses.

Inbred line	N°	FAO maturity	Type of grain
PR1	6	350	Orange flint
PR2	4	380	Orange flint
A632	5	500	Yellow dent
Mo17	9	580	Yellow dent
B84	7	600	Yellow dent
L256	10	620	Orange flint
ZN6	2	640	Orange flint
P21	8	650	Orange flint
P465	3	720	Orange flint
PR4	1	770	Orange flint

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