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Can elite maize landraces help to improve forage yield and quality? A genetic analysis

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Abstract

Broadening the genetic base of maize breeding program is a significant concern for plant breeders, since it restricts the magnitude of genetic gain. Identification of promissory exotic elite maize (*Zea mays* L) germplasm would be useful to increase the genetic variation within typically used heterotic groups and to improve the forage yield and quality. This study is aimed to assess the genetic potential of a group of elite maize landraces to improve forage yield and quality related traits and to broaden the genetic base of three temperate heterotic groups. Mean values and landrace general combining ability effects (GCA_l) revealed that some landraces could be considered as a valuable genetic resource to broaden the current genetic base through introgression of forage yield and quality favorable alleles. When stover and ear dry matter yield were considered, ARZM17035 was the best landrace since it produced the best performing landrace × inbred line crosses that also were stable across environments. Additionally, this landrace showed high GCA_l. Considering quality traits, ARZM07134 was the most promising source of favorable alleles. The use of B73 as tester in a recurrent selection scheme would be the most efficient strategy, since both mentioned landraces crossed to B73, showed the highest yield and quality values. Additionally, evaluated traits were mainly controlled by additive effects, so it is expected to obtain a positive response by selection.

Keywords: germplasm enhancement, combining ability, heterotic groups, digestibility, stover

Introduction

Germplasm selection to develop new inbred lines is a critical step in a breeding program. New maize hybrids are produced using a narrowed genetic base because repeated recycling of currently used parental inbred lines. This limited genetic diversity used within current maize germplasm may increase genetic vulnerability to biotic and abiotic stresses and can potentially limit yield selection gains in a near future (Tallury and Goodman, 1999; Zhang et al, 2000; Yong et al, 2012). Even though breeding programs explore in the identification and utilization of new heterotic patterns, only Stiff Stalk × non-Stiff Stalk has been extensively exploited in temperate regions for grain production. These constrains do not differ in silage maize breeding because for a long time it was accepted that a good grain hybrid was also the most suitable for silage (Argillier et al, 2000). Additionally, despite several breeding companies have programs to develop genotypes to produce silage and biofuel, their germplasm currently used mostly corresponds to genotypes chosen for grain maize breeding (Barrière et al, 2010).

The introgression of useful genetic variability from exotic germplasm (term that includes germplasm not commonly used in breeding programs) can be an important strategy to broaden the genetic variability to improve maize forage yield and quality. This strategy has been proposed by several authors for different traits (Eberhart, 1971; Oyerbides-Garcia et al, 1985; Hallauer and Miranda, 1988; Holley and Goodman, 1988; Mungoma and Pollak, 1988; Iglesias and Hallauer, 1989; Pollak et al, 1991; Michelini and Hallauer, 1993; Holland and Goodman, 1995; Holland et al, 1996; Rodrigues and Chaves, 2002; Carena, 2005; Soengas et al, 2006; Delucchi et al, 2012; Yong et al, 2013a, b; Incognito et al, 2013; Vancetovic et al, 2015). Thus, landraces could contribute with desirable favorable alleles absent in elite germplasm used to develop elite inbred lines (Cohen and Galinat, 1984).

Landraces frequently exhibit a poor agronomic performance relative to improved and elite germplasm, especially if landraces are evaluated in environments different to their geographic origin. Since the final product in maize breeding programs are elite hybrids, evaluation of the landrace performances in crosses with inbred lines to estimate combining abilities is a useful tool to perform a preliminary selection for the most promising germplasm to establish new heterotic patterns (Beck et al, 1991). Although it is known the potential of maize landraces as source of favorable alleles to improve grain yield and quality and others agronomics traits, very little information exists about their contribution to enhance forage yield and quality.

In a research project similar to the Latin American Maize Project (LAMP, 1991; Salhuana et al, 1991)

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the Instituto Nacional de Tecnología Agropecuaria (INTA) in Argentina, evaluated 300 Argentine accessions crossed with four broad-based testers of local and exotic origin, and selected the best yielding 10% (thirty landraces) (Delucchi et al, 2012). Subsequently, we chose eight of these elite landraces based on plant height, racial form, and geographical origin to determine their potential to improve maize forage yield and quality. The objectives of this study were: (i) to evaluate the performance for forage yield and quality related traits of the eight elite maize landraces in crosses with inbred lines of different heterotic groups and (ii) to determine their genetic potential as sources of germplasm to develop forage maize hybrids.

Materials and Methods

Genetic materials

Eight elite maize landraces (ARZM01073, ARZM02023, ARZM03014, ARZM04062, ARZM06020, ARZM07134, ARZM14103, ARZM17035) belonging to the Germplasm Bank at INTA Pergamino were included in this research. These landraces were selected, as already mentioned, based on their plant height, racial form, and geographical diversity. A detailed description of these landraces can be found in Incognito et al (2013). These landraces were crossed to four inbred lines (B73, Mo17, LP122-2, and LP612) representative of different heterotic groups tipically used to form heterotic patterns commonly employed in temperate regions (Stiff Stalk Synthetic × Lancaster Sure Crop, Stiff Stalk Synthetic × Argentine Orange Flint, and Lancaster Sure Crop × Argentine Orange Flint). We have previously found that the crosses between these inbred lines showed forage yields comparable to commercial checks. B73 and Mo17 are inbred lines developed at Iowa State University and University of Missouri, respectively. B73 was used in many genetic, molecular, and genomic studies (Schnable et al, 2009; Yu et al, 2008), is highly related to many more recent derived inbreeds, and is the common parent of the Nested Association Mapping Population (McMullen et al, 2009). LP612 and LP122-2 are Argentine Orange Flint inbred lines developed by the INTA maize breeding program. LP612 was derived from a cross between P465, a public inbred line, and sources of resistance to corn rust (*Puccinia sorghi*) from North America followed by selection and recombination between the more tolerant families. LP122-2 was derived from the cross between LP122 and L196. No relationship was detected between LP612 and LP122-2 inbred lines (Olmos et al, 2014). The eight selected landraces were crossed to the four inbred parents using four isolation blocks in which, alternatively one inbred line was used as the male to pollinate at least 150 detasseled female parent plants of each landrace. Ears were harvested from these plants and equal amounts of seeds from each bulked to represent each landrace × line crosses. Commercial hybrid checks were Dekalb 747 MGRR2, SPS Megasilo CL, and San Pedro Florentino S10, which were originally developed for grain production, but are widely used for forage production in Argentina.

Experimental Procedures and Data Collection

The eight elite landraces, thirty two landraces × inbred crosses, six inbred × inbred crosses, and three commercial checks were evaluated during 2008/2009 (hereafter 2008) and 2009/2010 (hereafter 2009) growing seasons at two locations representative of the Buenos Aires Province dairy region. These locations were Virrey del Pino (VP) (34°49'S;58°43'O) and Vicente Casares (VC) (35°18'S;58°56'O). The year × location combinations will be called hereafter as: VP2008, VP2009, VC2008, and VC2009. In both locations, soil is classified as typical Argiudoll. Field experiments were conducted following a randomized complete block design with three replications. Experimental units consisted in two rows planted 0.50 m appart and 5 m long. Plots were overplanted and latter thinned to a final plant density of 80,000 plants ha^{-1}. Standard cultural practices were used. The whole plot were hand-harvested when the kernel milk line reached 2/3 of the way down the kernels at the center of the ear (Hunt et al, 1989). Measures of fresh weights of both vegetative and reproductive structures were determined. A representative sample from ten random plants per plot was dried with forced air at 55°C for 7 d, to estimate dry matter percentage and to perform the laboratory analyses. Dried samples were milled to a 1 mm particle size. On all samples, near infrared spectra were collected (NIRS 6500, NIRSystem Inc, Silver Spring, MD) between 1,100 to 2,500 nm at every 2 nm. Ear (iDE) and stover (iDS) *in vitro* dry matter digestibility were predicted by NIRS equations, calibrated by the enzymatic method (Gabrielsen, 1986). Stover dry matter yield (SY) in megagrams per hectare, ear dry matter yield (EY) in megagrams per hectare, iDS in percentage, and iDE in percentage were assessed in each experiment.

Statistical Analysis

Data were analyzed using a mixed model where blocks, environment (location × year combination) and genotype × environment interaction were considered random effects, and genotypes fixed effects. Proc MIXED from SAS statistical package (SAS Institute, 2009) was used for the analysis. Excluding commercial checks and inbred × inbred crosses, mean square corresponding to genotypes was partitioned following a Partial Diallel design, in order to estimate general combining ability for each group of parents [landraces (GCA_l) and inbred lines (GCA_i)] and specific combining ability for the interaction between them (SCAli). The estimation of combining ability across environments was performed according to the following model:

$$Y_{libE} = \mu + e_E + b(e)_{bE} + g_l + g_i + s_{li} + ge_{lE} + gl_{iE} + se_{liE} + \varepsilon_{libE}$$

where Y_{libE} is the value of the crosses of the landrace l, the inbred line i, Bth block within Eth environment; μ is the grand mean; e_E is the average effect of the E^{th} environment; $b(e)_{bE}$ is the effect of the B^{th} block within E^{th} environment; g_l is the GCA effect common to all crosses of l^{th} landrace; g_i is the GCA common effect to all crosses of the i^{th} inbred line, and S_{li} is the SCA effect common to all crosses produced by mating the l^{th} landrace with the i^{th} inbred line. ge_{lE} and ge_{iE} are interaction between GCA effects and environments, and se_{liE} is the interaction between SCA effects and environments. ε_{libE} is the random experimental error. When GCA or SCA sources of variation were significant in the analysis of variance, individual landrace and inbred GCA effects and SCA of each cross were tested for significance by calculating a two-tailed t tests, where $t = g_l/SEGCA_l$ or $g_i/SEGCA_i$ and $s_{li}/SESCA_{li}$. $SEGCA_l$, $SEGCA_i$, and $SESCA_{li}$ are the standard errors for combining ability effects that were estimated according to Singh and Chaudary (1977). Combining ability relative indexes (CARI) to evaluate the importance of GCA and SCA for landraces and inbred parents were calculated based on the following equations modified from Baker (1978):

$$CARI_l = 2k^2_{GCA_l} / (2k^2_{GCA_l} + k^2_{SCA_{li}})$$

$$CARI_i = 2k^2_{GCA_i} / (2k^2_{GCA_i} + k^2_{SCA_{li}})$$

in which $k^2_{GCA_l}$ and $k^2_{GCA_i}$ are the quadratic form (analogous to a variance component but referring to a fixed model) from GCA_l and GCA_i effects and $k^2_{SCA_{li}}$ is the quadratic form of SCA_{li} effects since total genetic variation of single-cross progeny is equal to twice GCA component plus the SCA component. k^2 were computed as:

$$k^2_{GCA_l} = (MS_{GCA_l} - MS_{(GCA_{lxe})})(bxExN_i)^{-1}$$

$$k^2_{GCA_i} = (MS_{GCA_i} - MS_{(GCA_{ixe})})(bxExN_l)^{-1}$$

$$k^2_{SCA_{li}} = (MS_{SCA_{li}} - MS_{(SCA_{lixE})})(bxE)^{-1}$$

where MS_{GCA_l}, MS_{GCA_i}, $MS_{SCA_{li}}$, $MS_{(GCA_{lxe})}$, $MS_{(GCA_{ixe})}$, and $MS_{(SCA_{lixE})}$ are mean squares of GCA_l, GCA_i, SCA_{li} and their corresponding interactions with the environment, respectively. *b*, *E*, N_l, and N_i are number of bloks or repetitions (in complete blocks design), environments, landraces, and inbred lines, respectively. We used the approach used by Bertoia (2001) that proposed that four results are possible from CARI's equations. When GCA and SCA effects are significant, CARI values range from zero to one and thus values closer to one indicate that GCA effects are more important than SCA effects, indicating that a specific hybrid's performance is highly predictable based on GCA. The other possibilities are CARI values equal to zero when GCA effects are non significant or equal to one, when SCA effects are non significant, or when both GCA and SCA effects, are non significant. In addition, we considered that when the interaction between GCA and SCA with the environment is higher than their main effects, k^2 is zero because is not possible to obtain negative estimations of variance. Also combining ability analysis was done and plotted for each environment separately when genotype × environment interaction was significant for the studied traits. This analysis allowed the inspection of the consistency of GCA estimates across environments. The combining ability analyses were performed with Genes Software (Aplicativo computacional em Genética e Estadística Experimental – www.ufv.br/dbg/genes/genes.htm).

Table 1 - Mean squares of stover dry matter yield (SY), ear dry matter yield (EY) (Mg ha^{-1}), *in vitro* digestibility of stover dry matter (iDS) and in vitro digestibility of ear dry matter (iDE) (%) from combined analysis of variance including eight maize landraces, 32 maize landrace × inbred crosses, six inbred × inbred crosses and three commercial checks, across four environments. The ability to predict hybrid performance based on landrace and inbred line GCA values is measured by Combining ability relative indexes ($CARI_l$ and $CARI_i$, respectively).

		Mean Squares			
Source of variation	Df	SY	EY	iDS	iDE
Environment (E)	3	879.62**	1391.06**	1116.37**	826.03**
Blocks/E	8	4.35	2.34	15.82	12.83
Genotypes (G)	48	16.34**	29.47**	12.54†	16.61**
Crosses	31	15.04**	9.45**	8.09*	9.48**
GCA_l	7	43.27**	15.48**	7.85†	8.58**
GCA_i	3	6.17	18.39	29.73†	56.21**
SCA_{li}	21	6.90	6.17**	5.08	3.11
G × E	144	6.15**	4.47**	8.75**	3.51**
Crosses × E	93	6.20**	3.28**	5.01	2.50
GCA_l × E	21	9.80**	2.41**	3.87	1.63
GCA_i × E	9	8.82**	9.23**	8.84*	8.81**
SCA_{li} × E	63	4.62**	2.71**	4.84	1.89
Pooled error	384	2.21	1.00	4.65	1.93
$CARI_l$		1	0.65	1	1
$CARI_i$		1	0	1	1

†,*,** significant at the 0.1, 0.05, and 0.01 probability level, respectively.

Table 2 - Means of stover dry matter yield (Mg ha^{-1}) of eight landraces, 32 maize landrace × inbred crosses, six inbred × inbred crosses and three commercial checks, and estimates of general combining ability for landraces (GCA_l) and inbred lines (GCA_i) across four environments.

Genotypes	Means† (MG ha^{-1})					GCA$_l$ (MG ha^{-1})
		Landrace × inbred crosses				
Landraces	Landraces *per se*	B73	LP122-2	LP612	Mo17	
ARZM01073	5.8	7.3	7.9	9.3	6.5	-0.9**
ARZM02023	6.2	7.5	6.6	7.1	6.9	-1.6**
ARZM03014	9.7	8.3	10.1	8.8	8.8	0.3
ARZM04062	8.9	10.3	9.2	9.8	9.4	1.0**
ARZM06020	8.3	10.6	9.8	8.8	8.7	0.8**
ARZM07134	8.8	8.1	7.5	8.3	9	-0.4*
ARZM14103	8.9	9.4	8.2	8.6	8.5	-0.01
ARZM17035	8.2	10.6	9.8	8.6	9.2	0.9**
Inbred lines			inbred × inbred crosses			GCA$_i$
B73			9.6	9.4	8.3	0.3
LP122-2				10.9	8.7	-0.03
LP612					9.7	-0.01
Mo17						-0.3
Checks	Dekalb 747 MGRR2		San Pedro Florentino S10		SPS Megasilo CL	
	9.4		10.3		9.2	

†LSD (0.05) = 1.19 Mg ha^{-1}.
*, ** significant at the 0.05, and 0.01 probability level, respectively.

Results

Genotypes, Crosses, and GCA_l varied significantly for all traits, whereas GCA_i only differed for digestibility traits and SCA for EY (Table 1). The interaction G × E and GCA_l × E was significant for all traits but Crosses × E, GCA_i × E and SCA_{li} × E only showed differences for yield traits. We observed for all traits that $CARI_l$ and $CARI_i$ values (except to $CARI_i$ for EY) were close or equal to one, indicating that GCA is useful to identify the best landrace parents based on cross performance with a single representative tester. By contrast, $CARI_i$ value for EY was equal to zero, indicating that SCA is very important for this trait and that the evaluations in crosses with multiple testers will be required to identify superior hybrids (Hallauer and Miranda, 1988).

Stover Yield

Seven landraces × inbred line crosses and one per se landrace showed mean values that did not differ significantly from the highest yielding genotype (LP122-2 × LP612). The mean value of the two highest yielding landrace × line crosses (ARZM06020 × B73 and ARZM17035 × B73) exceeded significantly the second highest yielding commercial check (Dekalb 747MGRR2) (Table 2). Crosses with higher SY were those produced by ARZM04062, ARZM06020, and ARZM17035 using B73 and LP122-2 as testers, which also showed the highest GCA_l effects across environments (Table 2). Additionally, GCA_l values of these landraces for each environment were significantly positive or positive but not different from zero (Figure 1A). Although GCA_i effects did not differ significantly, it is important to note that B73 was the only inbred parent that showed positive value of GCA_i.

Ear yield

As expected, the commercial check selected for their high grain yield potential, DK 747MGRR2, was the highest yielding genotype for EY but interestingly a landrace × inbred cross, ARZM17035 × B73, did not differ from the five best inbred × inbred crosses. Three landrace × inbred crosses exceeded significantly San Pedro Florentino S10 and SPS Megasilo CL hybrid checks (Table 3). Additionally, EY of other ten landrace × inbred crosses were within one LSD with the two checks mentioned above. Several landrace parents that produced the highest yielding landrace × inbred crosses for SY also showed the highest EY crossed by B73 and both flint tester.

ARZM03014, ARZM14103 and ARZM17035, showed positive and significant GCAl values across environment, whereas ARZM04062 and ARZM06020 had GCA_l values positive but not significantly different from zero (Table 3). According to the results obtained from the diallel analysis for each tested environments, (Figure 1B), landrace parents exhibited significantly positive GCA_l values for all environments with the exception of ARZM17035 in VP2008 and ARZM03014 in VC2008 that had GCA_l values that did not differ from zero. All testers except Mo17, showed the capacity to increase EY although the GCA_i effects were not significant. Seven landrace × inbred crosses exhibited significantly positive SCA_{li} values (data not shown). ARZM17035 was the landrace parent that combined the best performing crosses with high GCA_l. Additionallly, ARZM17035 × B73 showed one of the highest SCA_{li} values. Also, we observed that SCA_{li} values for this landrace × inbred cross were significantly positive for all tested environments with the exception of VP2008 (data not shown). We also

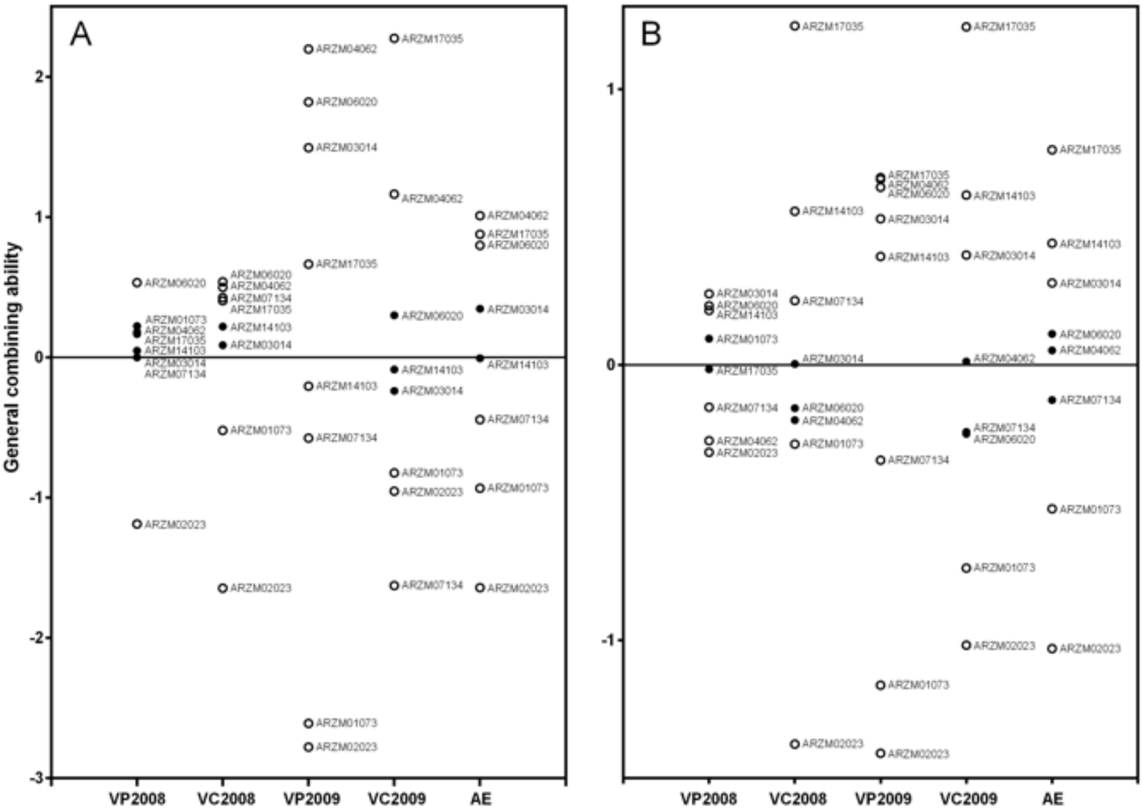

Figure 1 - Landrace general combining ability (GCAl) for stover (A) and ear dry matter yield (B) in (Mg ha-1) for Virrey del Pino 2008-2009 (VP2008) and 2009-2010 (VP2009), Vicente Casares 2008-2009 (VC2008), and 2009-2010 (VC2009), and across environments (AE). Full symbols indicate that GCA_l values not differ from zero at the 0.05 probability level for individual and across environments. Empty symbols indicate that GCA_l values differ from zero at the 0.05 probability level for individual and across environments.

found that flint × flint and flint × dent inbred × inbred crosses were the best performing genotypes, whereas crosses between dent × dent heterotic groups did not exhibited good performance.

***in Vitro* Digestibility of Stover**

The iDS values across environments indicate that six out of the eight landrace parents and eight landrace × inbred crosses were not significantly different from the two best commercial checks. Additionally, a large number of landrace × inbred crosses had mean values that did not differ from the second more digestible commercial check (Table 4). As expected for their breeding degree for grain yield and if we considered groups of genotypes, on average the decreasing order for iDS was landrace parents, landrace × inbred crosses, inbred × inbred crosses, and the worst performing genotype was the commercial check DK 747MGRR2. Landrace ARZM07134 produced the best performing crosses followed by ARZM06020. Crosses using B73 as tester exhibited high iDS values while, landrace × LP122-2 crosses, showed the lowest iDS values.

According to the diallel analysis across environments and coincidently with high mean values, the best landrace parent to produce crosses with high iDS was ARZM07134, whereas ARZM03014 and ARZM06020 also had positive GCA_l values but not different from zero (Table 4). Three out four inbred parents had positive GCA_i values but only B73 used as tester increased significantly the iDS across environments. Additionally, in the analysis for each environment, this inbred parent also showed positive and significant GCA_i values in VP2008 and VC2008, whereas in VC2009 had positive GCAi value that not differed from zero (data not shown). LP122-2 was the inbred parent that produced the worst performing landrace × inbred crosses.

***in Vitro* Digestibility of Ear**

Crosses between ARZM07134 with both dent testers, did not differ significantly from the two best commercial checks and from three inbred × inbred crosses (Table 5). Further, almost a 50% of the landrace × inbred crosses had mean values that did not differ from the second best commercial check. On average, the best performing landrace × inbred crosses were produced by ARZM07134 and ARZM14103,

Table 3 - Means of ear dry matter yield (Mg ha^{-1}) of eight maize landraces, 32 maize landrace × inbred crosses, six inbred × inbred crosses and three commercial checks, and estimates of general combining ability for landraces (GCA_l) and inbred lines (GCA_i) across four environments

Genotypes	Means† (MG ha^{-1})					GCA_l (MG ha^{-1})
		Landrace × inbred crosses				
Landraces	Landraces *per se*	B73	LP122-2	LP612	Mo17	
ARZM01073	4.2	6	7.2	8.2	5.8	-0.52**
ARZM02023	4.2	5.3	6.8	7.5	5.6	-1.03**
ARZM03014	5.4	7.9	8.6	7.4	6.7	0.30*
ARZM04062	4.9	8.3	7.2	7.1	7	0.05
ARZM06020	5.1	8.2	7.9	6.9	6.8	0.11
ARZM07134	5.2	6.9	7.4	7.2	7.4	-0.13
ARZM14103	6.8	7.9	8.1	8.1	7.1	0.44**
ARZM17035	6.1	9.5	8.1	7.6	7.3	0.78**
Inbred lines			inbred × inbred crosses			GCA_i
B73			9.8	9.2	7.7	0.2
LP122-2				9.9	9.3	0.3
LP612					9.2	0.2
Mo17						-0.6
Checks	Dekalb 747 MGRR2	San Pedro Florentino S10		SPS Megasilo CL		
	12.6	8.5		8.2		

†LSD (0.05) = 0.8 Mg ha^{-1}.
*, ** significant at the 0.05, and 0.01 probability level, respectively.

whereas crosses using B73 as tester showed high iDE values.

Based on GCA_l effects and coincidently with the highest iDE mean values, ARZM07134 and ARZM14103 landrace parents had positive and significant iDE values across environments (Table 5). In addition, the other landraces with exception of ARZM04062 and ARZM06020, showed GCA_l values that did not differ from zero. Positive GCA_i values were exhibited by both dent testers but only B73 increased significantly the iDE. When the analysis is performed by environment, B73 also showed significantly positive GCA_i values for all environments (data not shown).

Discussion

Most maize hybrids recommended for silage production have been based on grain yield improvement because breeders follow the general assumption that a good maize hybrid for grain is also good for silage. However, this assumption should be reviewed critically because when the purpose is to obtain silage maize hybrids, vegetative and reproductive fraction should be taken into account since whole plant is harvested and both fractions contribute to final dry matter yield (Pollmer, 1978). The development of temperate maize hybrids was largely based on the use of the Reid × Lancaster heterotic pattern, which leaded to an unintentional narrowing of the genetic base in this crop. Thus, the introgression of genes from exotic germplasm, can contribute favorable novel alleles that are not present in elite crop gene pool (Holland, 2004). In this way, landraces can be a valuable genetic resource to broaden the genetic base of elite breeding pools. In agree with this, our results reveal that some elite landraces had a performance comparative to commercial checks when they were crossed by an appropriate tester.

Corn forage yield increases can be explained by higher grain yield of new hybrids, but this trend can change if corn forage breeding focuses their efforts on the stover fraction (Lauer et al, 2001). The best performing genotype for SY in our study was LP122-2 × LP612 and we also found that flint × flint and flint × dent inbred line crosses were the best performing genotypes, whereas crosses between dent × dent heterotic group did not exhibited good performance, in agreement with Bertoia et al (2002). Coincidently, in their research they showed that inbred lines derived from Argentine landraces had more potential to increase SY than inbred lines from the North American Corn Belt. Additionally, W605S silage inbred line (developed from the Argentine breeding landrace ARZM17026 by the USDA Germplasm Enhancement of Maize Project) produced crosses with SY that did not differ significantly from the best commercial hybrid (Lorenz et al, 2009) showing the great potential of Argentine landraces to improve SY.

Several landraces produced good performing crosses for SY. High forage production of accessions from Argentina were also found by Nass and Coors (2003). Argentine landraces that improved the SY were also identified based on the fact that this accessions exhibited crosses with high SY and positive GCA_l values (Bertoia et al, 2006). Additionally, reviewing the literature to examine the relation between stover and grain yield, Lorenz et al (2010) indicated that the simultaneous improvement of grain yield and SY is possible since there were no nega-

Table 4 - Means of *in vitro* digestibility of stover dry matter (%) of eight maize landraces, 32 maize landrace × inbred crosses, six inbred × inbred crosses and three commercial checks, and estimates of general combining ability for landraces (GCA_l) and inbred lines (GCA_i) across four environments.

Genotypes	Means† (%)					GCA_l (%)
		Landrace × inbred crosses				
Landraces	Landraces *per se*	B73	LP122-2	LP612	Mo17	
ARZM01073	44.3	42.6	41.1	42	42.2	-0.31
ARZM02023	42.2	44	41.5	41.4	42	-0.05
ARZM03014	43.7	43.2	41	42.9	43.1	0.28
ARZM04062	43.5	42.3	40.6	42.5	41.7	-0.51*
ARZM06020	44.7	42	42.5	43	42.9	0.34
ARZM07134	42.8	44.3	41.9	43.4	42.2	0.68*
ARZM14103	43.4	41.7	41.8	42.3	41.8	-0.35
ARZM17035	43.7	42.5	41.6	42.2	42.5	-0.08
Inbred lines			inbred × inbred crosses			GCA_i
B73			43.4	43.2	42.4	0.56**
LP122-2				41.8	39.7	-0.76**
LP612					41.3	0.18
Mo17						0.03
Checks	Dekalb 747 MGRR2	San Pedro Florentino S10		SPS Megasilo CL		
	41.3	43.5		43.7		

†LSD (0.05) = 1.11 %.

*, ** significant at the 0.05, and 0.01 probability level, respectively.

tive correlations reported. In the present study, we found that ARZM17035, selected as the best source of favorable alleles to improve SY, also would enhance EY due to the high GCA_l showed. Moreover, ARZM17035 × B73, that exhibited one of the highest SCA_{li} estimates, had EY comparable or superior to commercial checks.

When iDS is considered, we found a general trend in which genotypes with no breeding history like landraces, had more digestibility than inbred × inbred line crosses or DK 747MGRR2 commercial check. ARZM07134 and ARZM06020 were considered the best parent landraces because produced the more digestible crosses and had positive genetic effect. Although B73 was improved for grain yield, it was the unique tester that enhances iDS. In agreement with our results, inbred lines derived from three Argentinean origins had the highest stover digestibility among old, unusual and new accessions evaluated by Barrière et al (2010).

Taking into account iDE, ARZM07134 was the best performing landrace. Additionally, ARZM14103 also can be considered one of the best sources of favorable alleles to improve iDE. Both landrace parents not only produced good performing crosses but also showed high positive and significant GCA_l values. Except for ARZM04062 and ARZM06020, none of landrace would decrease iDE. As expected, dent testers produced the best performing crosses and additionally, only B73, was the tester that also showed positive and significant GCA_i. This difference can be expected due to starch degradability is higher for dent than flint corn (Philippeau and Michalet-Doreau, 1997) since dent genotypes have a higher percentage of floury starch that would increase starch degradation. On the other hand, flint genotypes would decrease iDE due to a higher vitreouness (Philippeau et al, 1999; Correa et al, 2002) like LP612 flint tester that showed negative and significant GCA_i. McAllister et al (1993) proposed that the more developed protein matrix in vitreous endosperm would inhibit starch degradation.

In summary, we found large differences between mean values and GCA effects that revealed that some landraces can be considered as a valuable genetic resource to introgress favorable alleles for forage yield and quality, in order to broaden the genetic base to produce silage hybrids. Our results show that selection of the best landrace parents depends on the target trait. Thus, when SY and EY were considered across environments, ARZM17035 is the best landrace since it produced the best performing landrace × inbred line crosses (high GCA_l). Moreover, ARZM17035 showed positive and significant GCA_l estimates for three of the four tested environments, which demonstrates that its performance would be stable across them (GCA_l in VP 2008 was positive but non significantly different from zero). Additionally, GCA_l (mainly due to additive effects) made a significant and important contribution for SY and EY ($CARI_l$ for SY = 1 and $CARI_l$ for EY = 0.65) similar to the results reported by Bertoia (2001). High values of GCA are indicative of a high frequency of favorable alleles, suggesting good potential for the use of these landraces as breeding materials in recurrent selection programs (Crossa et al, 1990). The use of B73 as tester in the recurrent selection scheme will be the most efficient strategy, since ARZM17035 × B73 showed

Table 5 - Means of *in vitro* digestibility of ear dry matter (%) of eight maize landraces, 32 maize landrace × inbred crosses, six inbred × inbred crosses and three commercial checks, and estimates of general combining ability for landraces (GCA_l) and inbred lines (GCA_i) across four environments.

Genotypes	Means† (%)					GCA_l (%)
		Landrace × inbred crosses				
Landraces	Landraces *per se*	B73	LP122-2	LP612	Mo17	
ARZM01073	79	81.3	81	80	79.9	-0.29
ARZM02023	79.5	81.3	81.5	81	80.6	0.24
ARZM03014	78.7	81.5	81.2	79.5	81.2	0.01
ARZM04062	77.7	81.6	80.4	78.9	80.8	-0.42*
ARZM06020	79.1	81.6	80	79	81.1	-0.40*
ARZM07134	80.9	82.6	81.6	80.3	82	0.78**
ARZM14103	79.8	82	80.7	80.7	81.5	0.33*
ARZM17035	80	81.9	80.2	79.5	80.9	-0.24
Inbred lines			inbred × inbred crosses			GCA_i
B73			82.7	81.3	82.3	0.9**
LP122-2				80.6	83	-0.03
LP612					80.6	-1.0**
Mo17						0.14
Checks	Dekalb 747 MGRR2	San Pedro Florentino S10		SPS Megasilo CL		
	83	81.7		82.1		

†LSD (0.05) = 1.1%

*, ** significant at the 0.05, and 0.01 probability level, respectively.

the highest SY and EY values of all crosses. Additionally, this cross exhibited high iDS and iDE.

Landrace ARZM07134 is the most promising source of favorable alleles when quality traits were considered. GCA_l effects were predominant for iDS and iDE, indicating that additive genetic effects mainly determine these traits. The same breeding strategy than for yield traits is recommended for quality traits since the best cross of this landrace were obtained with B73 as tester.

In agreement with our results, several previous works have demonstrated the usefulness of Argentine maize germplasm to broaden the maize genetic base currently used to produce silage hybrids. Bertoia et al (2002) proposed that inbred lines derived from Argentine germplasm such as flint lines PR4, ZN6, P465, and P21 can be used to improve forage yield and quality of elite maize hybrids typically composed by classic heterotic groups defined on the basis of grain yield in temperate environments. Additionally, F7103 and F7104, two inbred lines derived from Argentine maize germplasm, were among the more promising exotic genetic resources to improve cell wall digestibility in dent or flint elite germplasm (Barrière et al 2010).

Introgression of exotic genetic resources such as maize landraces in breeding programs is a time-consuming and laborious process that has frequently discouraged maize breeders. Linkage drag is a common problem that delays the transference of favorable alleles from exotic to elite germplasm. Greater efforts for combining phenotype-based and marker-based methods could enhance the assessment of germplasm collections and accelerate their introgression, increasing the likelihood to develop inbred lines with high forage yield and quality. We are currently performing a recurrent selection scheme, deriving inbred lines from ARZM17035 and ARZM07134 using B73 as tester to improve forage yield and quality, respectively.

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