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Heterosis and heterotic patterns among maize landraces for forage

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ABSTRACT - *Corn silage is a high-quality forage crop used in many areas of the world. Although vegetative and reproductive components of the plant must be considered, breeding programs in temperate regions are mainly based on the Reid x Lancaster heterotic pattern that has undergone several cycles of improvement for grain yield. Moreover, hybrids selected for forage production are early maturing genotypes not adapted to warm-temperate or subtropical areas. Consequently, exotic germplasm should be considered as a source of materials for breeding programs. Eight landraces were crossed following a diallel mating design. Interpopulation crosses showed high heterosis for ear, stover, and whole plant dry matter yield (EY, SY, and WY, respectively). On average, crosses had higher SY than checks, but lower EY. Considering WY, two interpopulation crosses had higher means than all commercial checks, indicating the potential of the germplasm evaluated. Two composites were selected and different breeding strategies are discussed.*

Key words: Forage maize, composites, diallel analysis.

INTRODUCTION

Corn silage is a high-quality forage crop used in many areas of the world, which help dairy and cattle farmers to maintain a relatively constant forage supply during the year. It is used in mass due to its high yield, energy and digestibility.

Even though any maize forage breeders must consider the vegetative and reproductive components of the maize plant (Barriere and Traineau 1986, Dhillon et al. 1990, Argillier et al. 1995), temperate breeding programs largely rely on the use of the Reid x Lancaster heterotic pattern that has undergone several cycles of improvement, primarily for grain yield. Additionally, hybrids developed for superior forage production are early maturing genotypes not adapted to warm-temperate or subtropical areas. Consequently, under these climates, exotic germoplasm should be considered as a source of material for breeding programs devoted to the development of hybrids with good forage production. According to Crossa et al. (1990), in the Americas there is a tremendous genetic diversity in maize, as a result of thousands of years of evolution under domestication and hybridization, which has not been effectively exploited. Many authors have suggested the usefulness of incorporating exotic germplasm into breeding programs (Eberhart 1971, Hallauer and Miranda 1981, Oyerbides-Garcia et al. 1985, Holley and Goodman 1988, Mungoma and Pollak 1988, Iglesias and Hallauer 1989, Pollak et al. 1991, Michelini and Hallauer 1993, Rodrigues and Chaves 2002, Carena 2005, Soengas et al. 2006).

Thompson (1968) found that a group of exotic and semi-exotic populations yielded on average 28% more digestible dry matter than adapted hybrids, and Stuber

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(1986) suggested that some semi-exotic materials might be suitable for silage, given their good grain production and great vegetative development. Bosch et al. (1994) showed that some tropical maize populations produced high total digestible dry matter yields in semi-exotic crosses with B73 and MO17 inbred lines. Bertoia (2001) noted that landraces with no history of breeding for grain production generated crosses with good forage potential. Additionally, inbred lines from the North American Corn Belt did not demonstrate potential for enhanced stover yield and quality when compared with inbred lines from Argentine germplasm (Bertoia et al. 2002). According to Vencovsky and Miranda Filho (1972), Miranda Filho (1974), Rodrigues and Chaves (2002), Oliveira et al. (2006), Kutka and Smith (2007), composites are appropriate for use as base populations in breeding programs. Composites are obtained by intercrossing two or more open pollinated varieties with the objective of obtaining a new population with high genetic variability (and a high mean for the traits of interest). Miranda Filho and Chaves (1991) brought the theoretical basis of a procedure for selecting composites based on parameters defined in Gardner and Eberhart (1966) model II for diallel crosses.

The objectives of the present study are i) to select suitable landrace combinations to form composites for forage production adapted to temperate and warm-temperate areas, ii) to propose possible heterotic patterns among them, and ii) to define breeding strategies.

MATERIAL AND METHODS

Eight maize landraces were evaluated, representing differences in agronomic response, geographic origin, maturity, height, and grain type: ARZM 17-034 (32º13'S - 65º53'W, 906 growing degree days (GDD), 2.64 m, white dent), ARZM 03-056 (29º21'S – 59º59'W; 897 GDD; 2.59 m; white dent), ARZM 01-150 (37º11'S - 62º45'W; 865 GDD; 2.60m; white dent), ARZM 03-054 (29º24'S – 59º41'W; 858 GDD; 2.39 m; white dent), ARZM 16-062 (34º55'S – 67º32'W; 795 GDD: 2.30 m; yellow dent), ARZM 16-042 (33º47'S – 69º03'W; 752 GDD; 2.26 m; orange flint), ARZM 19-006 (37º04'S – 69º09'W; 683 GDD; 2.19 m; orange flint), ARZM 01-088 (38º06'S – 62º14'W; 666 GDD; 2.25 m; orange flint). Seeds were supplied by the Maize Germplasm Bank at INTA Pergamino, Argentina. Landraces were crossed following a diallel mating design without reciprocals. Crosses were performed in eight isolation blocks. In each isolation block, one population was used as the male and the other seven populations were detasseled and used as females. At least 150 ears per cross were obtained. Landraces per se, the 28 F1 crosses, and four commercial check hybrids (Cargill Semiden 5, Dekalb 4F37, Morgan 369, and Syngenta Pucara, selected for grain production but widely used for forage production in Argentina) were evaluated during two growing seasons (1997-1998; 1998-1999) at Esteban Echeverría (34º83'89'' S, 58º84'89'' W) and Vicente Casares (35º81'89'' S, 58º85'69'' W) in the Buenos Aires Province dairy region. Soils are typical Argiudoll (Vicente Casares) and Aquic Argiudoll with silty clay loam and B2t horizon (Esteban Echeverría).

The experimental design was a randomized complete block with three replications within each environment. Experimental units consisted of two 5.20-m rows, spaced 0.70 m apart. Plots were over-planted at 52 seeds per row, then thinned to a density equivalent to 71,500 plants ha^{-1} at the three-leaf stage. Each experimental unit was harvested by hand when the kernel milk line in approximately 50% of the plants reached two-thirds of the way down the kernels at the central part of the ear (Hunt et al. 1989). Ear and stover were separated and weighed fresh. A representative sample of each plant component was taken, weighed fresh, and dried with dry forced air, then weighed dry to provide an estimate of dry matter percentage. Stover (SY), ear (EY), and whole plant dry matter yield (WY) were determined. Dried samples were milled to a 1-mm particle size and analyzed with near-infrared reflectance spectroscopy. Near infrared spectra between 1,100 and 2,500 nm at every 2 nm were collected on all milled samples using an NIRS 6500 spectrophotometer (NIRSystem Inc., Silver Spring, MD). In vitro dry matter digestibility of ear (ED) and stover (SD) were predicted by NIRS equations, which were calibrated by the enzymatic method (Gabrielsen 1986). Whole-plant dry matter digestibility (WD) was $\%WD = \%ED \times 100^{-1} \times HI + \%SD \times 100^{-1} \times (1-HI)$. Where HI is the forage harvest index ($EY \times WY^{-1}$).

Diallel cross analysis

Analyses of variance were performed for each variable, using a mixed model where environments and genotype x environment interactions were considered random effects. Data corresponding to landraces and all possible crosses among them (excluding reciprocals) were analyzed according to Gardner and Eberhart (1966), by the following model:

$$Y_{ij} = U_v + ½ (v_i + v_j) + h_{ij}$$

$$\text{with } h_{ij} = h + h_i + h_j + s_{ij}$$

where:

Y_{ij} = Mean of the cross between landraces *i* and *j*, U_v = mean of all landraces, v_i = variety effect of landrace *i* (difference between the mean of a parent *per se* and the mean of all parents), h_{ij} = mid-parent heterosis effect, *h* = average heterosis (mean of all crosses minus the mean of all landraces), h_i = variety heterosis effect (heterosis contributed by cultivar *i* in those crosses in which it is present, measured as a deviation from the average heterosis effect), and s_{ij} = specific heterosis effect in the cross between landraces *i* and *j*.

Composite selection

All of the predictions were based on formulas outlined by Miranda Filho and Chaves (1991). The predicted mean of a composite (*Yc*) of *k* components was calculated by:

$$Y_c = U_v + \frac{1}{k}\sum_{i=1}^{k} vi + \left(\frac{k-1}{k}\right)h + \frac{2(k-1)}{k^2}\sum_{i=1}^{k} hi + \frac{2}{k^2}\sum_{i<j=2}^{k} sij$$

where:

k = size of the composite (number of landraces), and U_v, v_i, *h*, h_i, and s_{ij} are as defined above. Based on these parameters, the relative contribution of each cultivar to any composite mean can be determined for each composite size (*k*) using the following index (Miranda Filho and Chaves 1991):

$$I_i = ½\, v_i + [(k-1) / k]\, h_i$$

I_i and Y_c were used to estimate the relative contribution of each cultivar to the mixture mean and to predict the mean of selected composites, respectively. Means across all locations of each year were used to calculate these parameters.

RESULTS AND DISCUSSION

According to the combined analysis of variance, genotypes varied significantly ($P < 0.01$) for SY, EY, and WY (Table 1), but not for digestibility traits (SD, ED, and WD, not shown). Variations among checks were observed for SY and EY ($P < 0.01$), but not for WY.

Table 1. Analysis of variance for stover (SY), ear (EY), and whole-plant dry matter yield (WY) of eight maize landraces, 28 interpopulation crosses, and four commercial checks

Source of variation	df	SY (Mg ha^{-1})	EY (Mg ha^{-1})	WY (Mg ha^{-1})
		Mean Squares		
Environments (E)	3	235.2**	307.0**	845.0**
Replications	8	21.2**	7.9**	48.0**
Genotypes	35	30.9**	6.4**	43.0**
Varieties (v_j)	7	132.8**	14.8**	155.4**
Heterosis (h_{ij})	28	5.4*	4.3*	15.3**
Average heterosis (*h*)	1	51.8*	90.3**	278.9**
Variety heterosis (h_i)	7	2.9	0.8	3.3
Specific heterosis (s_{ij})	20	3.9	1.3	6.3
Checks	3	24.6**	14.4**	6.0
Checks vs Genotypes	1	983.3**	77.7**	3.0
Genotype × E	105	3.5**	2.5**	7.0**
v_j × E	21	4.4**	4.8**	14.0**
h_{ij} × E	84	3.2**	1.9**	5.8*
h × E	3	6.3	3.8**	14.9*
h_i × E	21	3.9**	2.2**	6.9*
s_{ij} x E	60	2.9**	1.7**	5.0**
Checks × E	9	4.6**	1.3**	8.0**
(Checks vs. Genot.) × E	3	11.8**	1.0	20.0**
Pooled error	312	1.2	0.9	3.0

*, **, Significant at 0.05 and 0.01 probability levels for an F test, respectively

The difference between commercial hybrids and experimental genotypes was significant for SY and EY ($P < 0.01$). On average, checks had greater EY but lower SY than the unimproved genotypes (Table 2). No landraces or crosses had EY as high as the best check, Dekalb 4F37 (8,935 kg ha^{-1}), but crosses BxG (7,940 kg ha^{-1}) and DxG (7,767 kg ha^{-1}) did not show significant differences with the second best check (Cargill Semiden 5 with 8,449 kg ha^{-1}) and had better EY than Morgan 369 (6,454 kg ha^{-1}) (Table 2). SY of crosses AxB (12,883 kg ha^{-1}) and AxD (13,229 kg ha^{-1}), were significantly greater than the best check, Morgan 369 (11,894 kg ha^{-1}). WY ranged from 10,893 kg ha^{-1} for landrace H, to 20,329 kg ha^{-1} for the cross AxD, which together with cross AxB (19,814 kg ha^{-1}) showed significantly higher WY than all checks (Table 2). According to Gardner and Eberhart diallel model II (1966), variety effects (v_i), mid-parent heterosis effects (h_{ij}), and average heterosis (h), were significant for EY, SY, and WY. Specific heterosis (s_{ij}) and variety heterosis (h_i), did not show significant differences for any trait (Table 1). All effects x environment interactions were significant.

The combined analysis of variance indicates that variety effects accounted for 46% of the entries sum of squares for EY and 86% for SY, while mid-parent heterosis explained 54% and 14% respectively of the entries sum of squares. Landraces B (511 kg ha^{-1}), D (754 kg ha^{-1}), F (486 kg ha^{-1}), and G (508 kg ha^{-1}) showed positive and high v_i values for EY (Table 3). The highest v_i values for SY were observed in landraces A (1,680 kg ha^{-1}), B (2,244 kg ha^{-1}), C (727 kg ha^{-1}), and D (1,424 kg ha^{-1}). High values for varieties effects are indicative of a high frequency of favorable alleles, indicating good potential for the use of these landraces as breeding materials in recurrent selection programs (Crossa et al. 1990).

Crosses showed greater values than parental landraces for all yield traits, indicating significant mid-parent heterosis (h_{ij}). With the exception of crosses BxD, CxD and ExF for SY and BxF and CxD for WY, all h_{ij} effects were significant and relatively high (Table 3), ranging from 6.4 % to 29.2 % for EY, from -8.2 % to 19.4 % for SY, and from 4.3 % to 20.4 % for WY. Besides the high mid-parent heterosis observed in most crosses, high parent heterosis (h_{ii}, not shown but easily calculated from table 2) must be also taken into account, and only those crosses with high means should be considered. Thus, the best crosses for SY (AxB, and AxD) showed h_{ij} and h_{ii} (in parenthesis) values of 10.3% (7.7%) and 17.4% (16.1%) respectively, while for EY, cross AxD had values of 26.6% (11.1%), BxD 14.7% (12.5%), BxF 20.6% (20.4%), BxG 29.2% (29.1%), BxH 25.5% (16.2%), and FxG 16.6% (16.4%). Considering WY, crosses AxB and AxD showed heterosis values of 15.4% (9.4%) and 20.4% (15.8%), respectively. Several studies reported a high mean, h_{ij}, and/or h_{ii} values in interpopulation or line by population crosses (Miranda Filho and Vencovky 1984, Crossa et al. 1990, Perez-Velazquez 1995, San Vicente et al. 1998, Bertoia 2001, Mickelson et al. 2001, Reif et al. 2003, Soengas et al. 2006).

High means for EY, SY, and WY as well as high v_j and h_{ij} effects observed in some landraces and their crosses, make them suitable to be used as a germplasm source in breeding programs. The combination of landraces to form composites could be a good strategy that must be explored.

To evaluate composites among a group of landraces (n), the possible number of combinations (assuming equal proportions of each landrace in the composite) is $N_c = 2^n - (n+1)$ (Vencovsky and Miranda Filho 1972). As an example, with only 10 landraces, 1,013 different combinations can be obtained, making their synthesis and field evaluation prohibitive. Thus, the use of prediction procedures can be very helpful when a large number of entries to evaluate under field conditions is not possible. Miranda Filho and Chaves (1991), proposed a model to select composites. Measuring the relative contribution to the composite means (I_i) of each potential landrace to include, they selected only the most promising landraces, thereby reducing the number of possible combinations to test. Furthermore, they calculated the predicted means (Y_c) of the chosen combinations as an additional selection criterion. Y_c is a function of the effects defined in Gardner and Eberhart model II, as can be seen in the equation (1). Those effects are multiplied by weighting coefficients that modify their contribution to the predicted means in a quantity that is a function of the number of landraces (k). In this equation (1), for any composite size, the first and third terms are constants, and the fifth term is very small for large k ($2/k^2$ is negligible and Σs_{ij} tends to 0 when k tends to n). Thus, for each composite size, terms depending on v_i and h_i are important in selecting landraces to form composites. The relative contribution of each landrace to the mean of different composites (I_i) is defined as a function of both parameters (see equation 2). I_i and Y_c were used in this paper to select the most promising composites for forage production.

Table 2. Mean, and mid-parent heterosis (MPH) for ear, stover, and whole dry matter yield (EY, SY, and WY, respectively), across four environments for landraces, crosses among landraces, and commercial checks. Codes are in letters for landraces and in numbers for commercial checks: A = ARZM 17-034; B = ARZM 03-056; C = ARZM 01-150; D = ARZM 03-054; E = ARZM 16-062; F = ARZM 16-042; G = ARZM 19-006; H = ARZM 01-088; 1 = Morgan 369; 2 = Cargill Semiden 5; 3 =Syngenta Pucara; 4 = Dekalb 4F37

Genotype Code	EY		SY		WY	
	Mean Kg ha^{-1}	MPH%	Mean Kg ha^{-1}	MPH%	Mean Kg ha^{-1}	MPH%
A	4,826	—	11,398	—	16,224	—
B	6,148	—	11,962	—	18,110	—
C	5,574	—	10,445	—	16,019	—
D	6,391	—	11,142	—	17,533	—
E	4,657	—	9,644	—	14,301	—
F	6,123	—	8,820	—	14,943	—
G	6,145	—	8,673	—	14,818	—
H	5,232	—	5,660	—	10,893	—
A x B	6,932	26.3**	12,883	10.3**	19,814	15.4**
A x C	5,532	6.4**	12,634	15.7**	18,166	12.7**
A x D	7,100	26.6**	13,229	17.4**	20,329	20.4**
A x E	5,945	25.4**	11,624	10.5**	17,569	15.1**
A x F	6,490	18.5**	10,453	3.4*	16,943	8.7**
A x G	6,798	23.9**	11,461	14.2**	18,256	17.6**
A x H	6,503	25.6**	9,493	11.3**	15,997	18.0**
B x C	6,679	14.0**	12,580	12.3**	19,259	12.9**
B x D	7,188	14.7**	11,400	-1.3	18,588	4.3*
B x E	6,691	23.9**	11,471	6.2**	18,163	12.1**
B x F	7,400	20.6**	9,534	- 8.2**	16,935	2.5
B x G	7,940	29.2**	11,101	7.6**	19,040	15.6**
B x H	7,142	25.5**	9,540	8.3**	16,592	14.4**
C x D	6,598	10.3**	10,658	-1.3	17,256	2.9
C x E	6,646	29.2**	11,454	14.0**	17,901	18.1**
C x F	6,982	19.4**	10,401	8.0**	17,384	12.3**
C x G	6,917	18.0**	10,513	10.0**	17,430	13.0**
C x H	6,531	20.9**	9,617	19.4**	16,148	20.0**
D x E	6,232	12.8**	11,268	8.4**	17,500	9.9**
D x F	6,994	11.8**	11,208	12.3**	18,202	12.1**
D x G	7,767	23.9**	11,522	16.3**	19,289	19.2**
D x H	6,487	11.6**	8,916	6.1**	15,403	8.4**
E x F	6,297	16.8**	9,256	0.3	15,553	6.4*
E x G	6,919	28.1**	9,576	4.6**	16,495	13.3**
E x H	5,564	12.5**	8,723	14.0**	14,288	13.4**
F x G	7,153	16.6**	9,353	6.9**	16,506	10.9**
F x H	6,898	21.5**	7,966	10.0**	14,865	15.1**
G x H	6,511	14.5**	7,678	7.1**	14,189	10.4**
			Commercial Checks			
1	6,454	—	11,894	—	18,348	—
2	8,449	—	9,643	—	18,092	—
3	7,498	—	9,297	—	16,794	—
4	8,935	—	8,578	—	17,513	—
LSD (0.05)	752.1	—	893.6	—	1,386.5	—

*, **, Significantly different from zero at 0.05 and 0.01 probability levels for a t test, respectively

Table 3. Estimates of mean of landraces (U_v), variety effects (v_i), average heterosis (h),variety heterosis (h_i), and specific heterosis (s_{ij}) for ear, stover, and whole plant dry matter yield (EY, SY, and WY, respectively), according to Gardner and Eberhart Model II for a diallel cross among eight landraces (A to H), and predicted means of selected composites

	v_i	h_i	s_{ij}						
			Ear Dry Matter Yield (EY, kg ha^{-1})						
			B	C	D	E	F	G	H
A	-810.86	95.53	35.68	-649.68	471.97	28.70	-113.27	-103.21	329.81
B	511.29	213.20		-281.20	-218.95	-3.45	18.65	259.72	189.55
C	-63.51	-213.90			-94.72	465.82	314.95	-48.61	293.44
D	754.23	-175.95				-195.86	-119.69	354.52	-197.27
E	-980.50	-20.56					-105.42	218.23	-408.02
F	486.18	-67.17						-234.18	238.96
G	508.45	219.97							-446.47
H	-405.28	-51.12							
U_v = 5,637.06 ; h = 1,100.04									
			Stover Dry Matter Yield (SY, kg ha^{-1})						
			B	C	D	E	F	G	H
A	1,679.58	480.29	251.16	96.19	633.84	-166.73	-471.01	32.15	-375.61
B	2,243.66	-361.41		601.29	-635.84	240.34	-829.13	231.44	140.74
C	727.18	303.36			-1,283.66	317.05	130.64	-262.76	401.23
D	1,423.97	12.17				73.74	880.17	688.78	-357.03
E	-73.96	-43.46					-267.06	-452.10	254.75
F	-897.96	-498.22						191.49	364.91
G	-1,045.16	80.45							-429.00
H	-4,057.31	26.83							
U_v = 9,718.08 ; h = 832.78									
			Whole Plant Dry Matter Yield (WY, kg ha^{-1})						
			B	C	D	E	F	G	H
A	868.73	575.82	286.84	-553.48	1,105.81	-138.03	-584.28	-71.06	-45.79
B	2,754.95	-148.21		320.09	-854.79	236.89	-810.48	491.16	330.29
C	663.66	89.45			-1,378.38	782.88	445.59	-311.36	694.67
D	2,178.19	-163.78				-122.11	760.48	1,043.3	-554.30
E	-1,054.45	-64.02					-372.49	-233.88	-153.26
F	-411.78	-565.39						-42.69	603.86
G	-536.71	300.42							-875.47
H	-4,462.60	-24.29							
U_v = 15,355.14 ; h = 1,932.82									

	Predicted means				
Composite	**EY (kg ha^{-1})**	**Composite**	**SY (kg ha^{-1})**	**Composite**	**WY (kg ha^{-1})**
B-D	6,729	A-B	12,281	A-B	18,491
B-F	6,768	A-C	11,778	A-C	17,144
B-G	7,043	A-D	12,249	A-D	18,604
D-F	6,566	B-C	11,891	B-C	18,161
D-G	7,018	B-D	11,476	B-D	18,205
F-G	6,643	C-D	10,726	C-D	17,016
B-D-F	6,870	A-B-C	12,222	A-B-C	18,314
B-D-G	7,164	A-B-D	12,169	A-B-D	18,814
B-F-G	7,045	A-C-D	11,781	A-C-D	17,920
D-F-G	6,943	B-C-D	11,425	B-C-D	17,985
B-D-F-G	7,106	A-B-C-D	11,982	A-B-C-D	18,419
Average	6,900	Average	11,816	Average	18,098

I_i of each landrace was estimated for different composite sizes (k, from 2 to 8), for EY, SY, and WY (Figure 1, 2, and 3). Even tough variety heterosis (h_i) and specific heterosis (s_{ij}) were not significant for any trait, and they were not neglected in the estimates. Similarly, Miranda Filho and Chavez (1991) included s_{ij} effects in their estimates of Y_c, although they were non significant. I_i represents a useful parameter to select the most suitable landraces. For any given trait, positive estimates of I_i imply that when it is present, the i^{th} landrace contributes an increasing composite mean. For any k, Landraces B, D, F, and G had positive I_i values for EY, and landraces A, B, C, and D for SY. Composite size (k) is important because Ii tends to a general combining ability when k tends to ∞ (Miranda Filho and Chaves 1991), but depending on the magnitude and sign of v_i and h_i effects, I_i can be positive or negative, or simply increase or decrease, and the relative contribution of each landrace can change along k values. Landraces A, C, E, and H showed negative I_i estimates for EY, and landraces E, F, G, and H for SY. Landraces with negative values of I_i should be discarded, since they will reduce the mean of any possible composite (with these eight landraces) if included. Two hundred and forty seven composites can be synthesized with these eight landraces, but if those with negative Ii are discarded, 11 composites for EY and 11 for SY can be formed.

Table 3 shows the predicted mean of the selected composites. Predicted EY means varied from 6,566 kg ha^{-1} for composite D-F, to 7,164 kg ha^{-1} for composite B-D-G, with an average of 6,900 kg ha^{-1} for the 11 composites, similar to the lowest yielding hybrid, Morgan 369 (6,454 kg ha^{-1}). The predicted SY ranged from 10,726 kg ha^{-1} for C-D, to 12,281 kg ha^{-1} for A-B, with an average for the 11 composites of 11,816 kg ha^{-1}, similar again to Morgan 369 (11,894 kg ha^{-1}) that for SY is the best commercial hybrid. Considering WY, the selected landraces are A, B, C, and D, since they consistently showed positive I_i estimates. The predicted

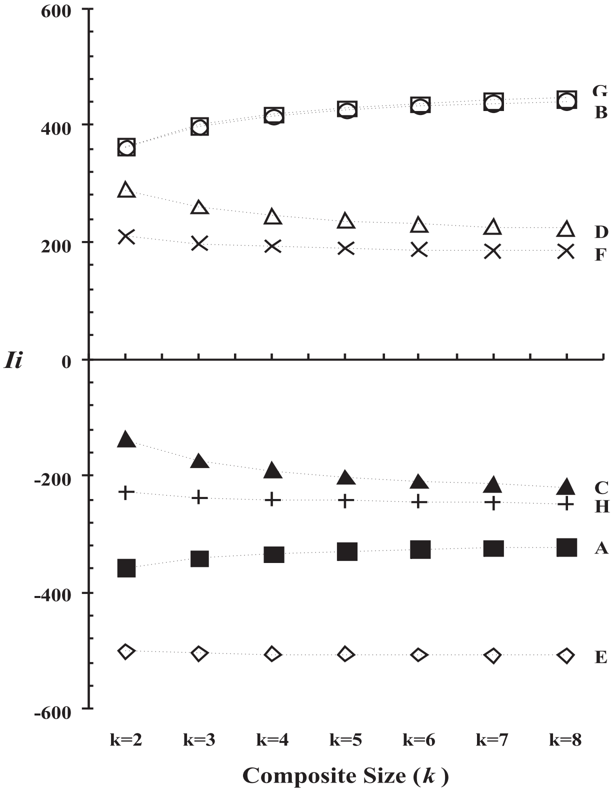

Figure 1. Relative contribution (h) of eight landraces to composite means for EY (kg ha^{-1}). Landraces codes are: A= ARZM 17-034; B= ARZM 03-056; C= ARZM 01-150; D= ARZM 03-054; E= ARZM 16-062; F= ARZM 16-042; G= ARZM 19-006; H= ARZM 01-088

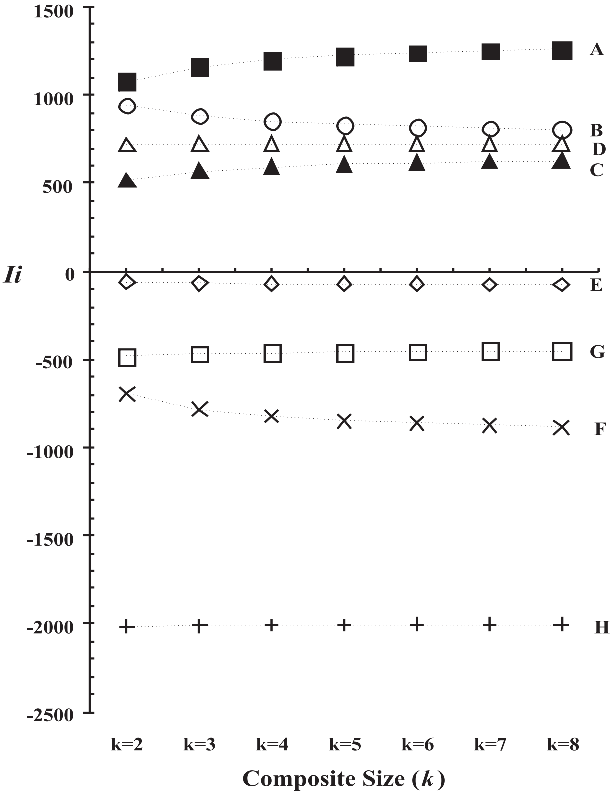

Figure 2. Relative contribution (li) of eight landraces to composite means for SY (kg ha^{-1}). Landraces codes are: A= ARZM 17-034; B= ARZM 03-056; C= ARZM 01-150; D= ARZM 03-054; E= ARZM 16-062; F= ARZM 16-042; G= ARZM 19-006; H= ARZM 01-088

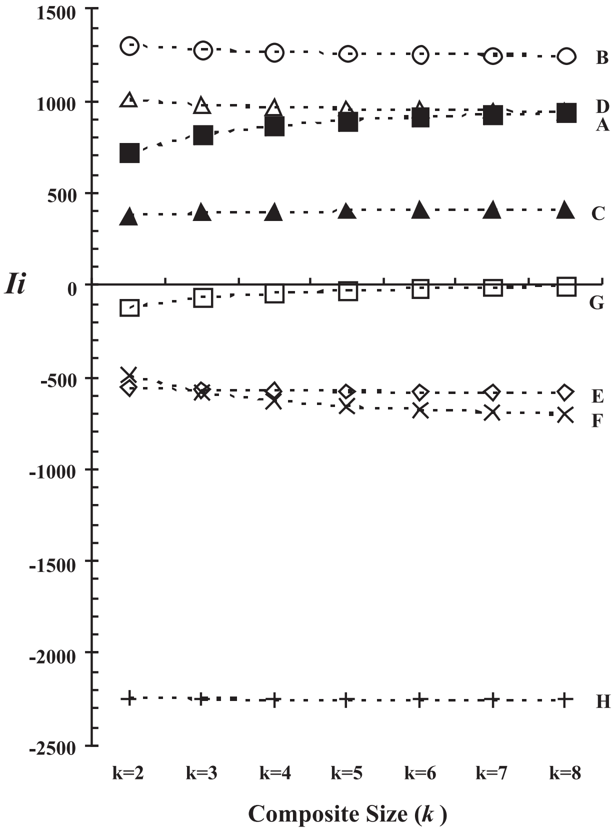

Figure 3. Relative contribution (*Ii*) of eight landraces to composite means for WY (kg ha^{-1}). Landraces codes are: A= ARZM 17-034; B= ARZM 03-056: C= ARZM 01-150; D= ARZM 03-054; E= ARZM 16-062; F= ARZM 16-042; G= ARZM 19-006; H= ARZM 01-088

composite WY means varied from 17,016 kg ha^{-1} (C-D) to 18,814 kg ha^{-1} (A-B-D). An average WY of 18,098 kg ha^{-1} show good potential for the selected composites, given that the average actual WY for checks was 17,687 kg ha^{-1}, and the best of them (Morgan 369) reached 18,348 kg ha^{-1}. Lopez and Mundt (2000), evaluated the ability of the Miranda and Chavez method for predicting means of wheat mixtures with different number of cultivars (3; 4; and 5), by comparing actual and predicted mixture means for yield (YLD) and diseased leaf area (DLA) under stripe rust infection (*Puccinia striiformis*). They showed significant Spearman´s rank correlation coefficients between predicted and actual values varying from 0.78 to 1, under different conditions.

Landraces A, B, C, and D, are good candidates to form a composite, since all have positive *Ii* for WY, SY, and EY, with the exception of A and C for EY. Even considering these negative *Ii* estimates, the results suggest that the best choice is composite A-B-C-D, because the predicted WY (18,419 kg ha^{-1}) is similar to other good composites of smaller sizes, but including a higher number of landraces will provide higher genetic variability. Additionally, the four populations have similar cycles and grain types, and the predicted mean for EY (6,447 kg ha^{-1}) is similar to one of the commercial hybrids (Morgan 369, 6,454 kg ha^{-1}). Another composite that can be considered is F-G, formed by two orange flint landraces with similar cycles, positive *Ii* for EY, and combining ability with landrace components of composite A-B-C-D.

Once A-B-C-D is synthesized, the development of recurrent selection schemes followed by the selection of inbred lines can be implemented following two strategies: i) the use of a semi-exotic heterotic patterns among A-B-C-D and inbred lines of well known heterotic patterns such as Reid, Lancaster or other inbred lines characterized by a high potential to increase forage quality (Jung et al. 1998, Argillier et al. 2000), or ii) the exploitation of the exotic heterotic pattern A-B-C-D x F-G, since diallel crosses among them showed high means and heterosis effects for WY, SY, and EY.

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Heterose e padrões de heterose entre raças de milho para forragem

RESUMO - *O milho forrageiro é uma cultura de alta qualidade usada para silagem em muitas áreas do mundo. Embora os componentes vegetativos e reprodutivos da planta devam ser considerados, programas de melhoramento em regiões temperadas, baseiam-se principalmente no padrão heterotico Reid x Lancaster, submetido a vários ciclos de seleção para* *melhoramento da produtividade de grãos. Além disso, híbridos selecionados para produção de forragem são genótipos precoces, não adaptados ao calor de zonas temperadas ou subtropicais. Consequentemente, germoplasma exótico deve ser considerado como fonte de genes para programas de melhoramento. Oito raças de milho crioulo foram cruzadas seguindo o modelo dialelo. Cruzamentos interpopulacionais apresentaram alta heterose no rendimento de espiga (RE), de palha (RP) e de matéria seca total (RM). Em média, os valores de RP para os cruzamentos foram superiores em relação aos controles; porém inferiores a RE. Com relação a RM, dois cruzamentos interpopulacionais tiveram médias superiores a todas as variedades comerciais, indicando o potencial do germoplasma avaliado. Dois compostos foram selecionadas e diferentes estratégias de melhoramento discutidas.*

Palavras-chave: Milho para silagem, compostos, dialelo.

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