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Breeding potential of S_4 maize lines in topcrosses for agronomic and forage traits

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ABSTRACT. This study aimed to evaluate the performance of 46 maize lines (S4) obtained from crosses between the commercial hybrids Penta x P30F53 in topcrosses with the commercial simple cross hybrid Dow8460 (tester) and checks (hybrids Penta, P30F53, Dow8460 and Status). The grain yield was evaluated in two environments in Guarapuava, Paraná State, and the effects of genotype, environment and genotype x environment interaction were significant. The grain yield of the topcross hybrids ranged from 8,416 to 13,428 kg ha^{-1}. The agronomic characteristics of the forage and the bromatological characteristics of the silage were evaluated in environment 1. The green mass yield of the forage ranged from 48,767 to 87,714 kg ha^{-1} and the dry mass yield ranged from 14,749 to 26,130 kg ha^{-1}. The neutral detergent fiber content ranged from 44.85 to 58.45% and the acid detergent fiber content ranged from 28.28 to 37.06%. The relative feed value of the silage ranged between 100.5 and 138.5. The tester, hybrid Dow8460, was efficient to discriminate the relative performance of the S4 lines in the topcrosses.

Keywords: *Zea mays*, acid detergent fiber, neutral detergent fiber, silage, plant breeding.

Potencial agronômico e forrageiro de linhagens S_4 de milho em *topcrosses*

RESUMO. Objetivou-se avaliar o comportamento de 46 linhagens S_4 de milho provenientes do cruzamento entre os híbridos comerciais Penta x P30F53 em *topcrosses* com o híbrido simples comercial Dow8460 (testador), mais as testemunhas (híbridos Penta, P30F53, Dow8460 e Status). A produtividade de grãos foi avaliada em dois ambientes em Guarapuava, estado do Paraná e houve efeito significativo de genótipos, ambientes e da interação genótipos x ambientes. Entre os híbridos *topcrosses* a produtividade de grãos variou de 8.416 a 13.428 kg ha^{-1}. No ambiente 1 foram avaliadas características agronômicas da forragem e bromatológicas da silagem. A produtividade de massa verde da forragem variou de 48.767 a 87.714 kg ha^{-1}e a produtividade de massa seca de 14.749 a 26.130 kg ha^{-1}. Os teores de fibra em detergente neutro da silagem variaram de 44,85 a 58,45% e os teores de fibra em detergente ácido de 28,28 a 37,06%. O valor relativo da silagem oscilou entre 100,5 e 138,5. Os híbridos *topcrosses* HTC 109 e HTC 183 foram superiores considerando todo o conjunto de caracteres forrageiros e bromatológicos da silagem e, ainda, apresentaram elevada produtividade de grãos, indicando que suas respectivas linhagens S_4 contribuíram com alelos favoráveis para as características avaliadas.

Palavras-chave: *Zea mays*, fibra em detergente ácido, fibra em detergente neutro, silagem, melhoramento genético.

Introduction

Maize is considered a model plant for the current use of silage in cattle feeding (Courtial et al., 2013) because it provides good quality feed with a high nutritional value (Salazar et al., 2010) and it has a high potential for forage and grain dry matter production (Alvarez, Von Pinho, & Borges, 2006).

Generally, Brazilian maize breeding programs have placed little emphasis on the development of specific hybrids for silage purposes; thus, the hybrids recommended for silage are usually the same as those for grain production (Gomes, Von Pinho, Ramalho, Ferreira, & Brito, 2004). The genetic basis of maize germplasm should be explored to improve the traits related to forage yield and quality (Nass & Coors, 2003; Incognito, Eyhérabide, Bertoia, & López, 2013).

Inbred lines are needed to obtain maize hybrids, which require large investments and attention of breeders, as well as good experimental precision (Nurmberg, Souza, & Ribeiro, 2000; Paterniani, Luders, Duarte, Gallo, & Sawazaki, 2006). Topcrosses are commonly used for this purpose (Nduwumuremyi, Tongoona, & Habimana, 2013). The topcross method is used to evaluate the relative merit of many partly inbred lines in crosses with testers, assisting in the decision to eliminate lines with lower performance (Paterniani et al., 2006; Aguiar, Schuster, Amaral Júnior, Scapim, & Vieira, 2008; Nelson & Goodman, 2008; Marcondes et al., 2015a).

Many studies have reported variability between commercial maize hybrids with respect to the dry matter yield of forage (Mello, Nornberg, Rocha, & David, 2005; Mendes, Von Pinho, Pereira, Faria Filho, & Souza Filho, 2008; Pinto et al., 2010; Mendes, Pereira, & Souza, 2015), and commercial hybrids can be used as a basis for obtaining new inbred lines for silage purposes. On the other hand, few studies have been carried out to evaluate maize topcrosses with emphasis on forage characteristics and bromatological quality of the silage to highlight the importance of choosing genotypes that combine high forage dry matter yield, low fiber content and high nutritional quality of the silage (Marcondes et al., 2015b).

The aim of this study was to evaluate the relative performance of S_4 maize partly inbred lines topcrossed with a narrow genetic base tester, with respect to the grain yield, forage yield and bromatological quality of the silage.

Material and methods

Forty-six partly inbred maize lines (S_4) were obtained from planting a selfed F_2 generation that resulted from crossing the commercial single-cross hybrids Penta and P30F53. These S_4 lines were topcrossed with a narrow genetic base tester, the commercial hybrid Dow8460, resulting in 46 topcross hybrids. These hybrids were chosen based estimates of grain yield (Pfann et al., 2009) and the bromatological characteristics of the forage (unpublished data).

The 46 topcrosses and four checks (hybrids Penta, P30F53, Dow8460 and Status) were evaluated in two experiments conducted in Guarapuava, Paraná State, Brazil: the first (environment 1) was carried out in the experimental field of the Universidade Estadual do Centro-Oeste, UNICENTRO (lat. 25°23'36"S, long. 51°27'19"W, 1,120 m asl); the second (environment 2) was carried out in the experimental area of the Três Capões Farm of the Santa Maria Company (lat. 25°25'60"S, long. 51°39'27"W, 990 m asl) in the 2011/2012 season.

In both environments, the experiments were carried out using a randomized block design with three replications. The experiments were performed in a no-till system, and the sowing dates for the two environments were 01/11/2011 and 02/11/2011, respectively. Plots consisted of two rows, 5 m in length, with a row spacing of 0.80 m in environment 1 and 0.45 m in environment 2, with a target plant density of 70,000 plants ha^{-1} at both locations.

Grain yield (GY) was evaluated in both environments. In environment 1, we evaluated the cycle (number of days) from male flowering to forage harvest (for silage purposes) (CFH) and the green mass yield (GMY) of the forage, using all plants from one row of each plot in two replications. The dry mass yield (DMY) of the forage was evaluated from samples of 0.3 kg of green material that were dried in a forced-air circulation kiln at 55°C until a constant weight. The GMY and DMY are expressed in kg ha^{-1}.

The forage harvesting was performed when the grains were at the 75% milk-line stage. For ensiling, six plants from each plot of two replications were manually cut at 20 cm above the soil surface and minced in particles of 2 cm. Then, the material was ensiled in PVC (polyvinyl chloride) experimental silos with a 10 cm diameter and a 45 cm length. After 120 days, the silage dry matter (DM) was determined based on a 0,3 kg sample that was dried in an air-forced circulation kiln at a temperature of 55°C until a constant weight. Subsequently, the samples were ground in a Wiley mill, in particles of 1 mm for carrying out bromatological analyses.

Bromatological analyses were performed in the laboratory: the neutral detergent fiber (NDF) and acid detergent fiber (ADF) was analyzed according to Van Soest, Robertson, Lewis (1991); the mineral matter (MM) content was determined following Association of Official Analytical Chemists (AOAC, 1990); the crude protein (CP) and nitrogen content was determined following AOAC (1990) using the Kjeldal method according to Silva and Queiroz (2002); and the dry matter (DM) was determined following AOAC (1990). All analyses were performed in duplicate. The data obtained were used to estimate the non-fibrous carbohydrate content plus ether extract (NFC + EE) according to National Research Council (NRC, 2001), and the total digestible nutrients (TDNs) and relative feed value (RFV) of the silage following Bolsen (1996).

The agronomic and bromatological characteristics of each experiment were submitted to individual variance analysis. The homogeneity of the residual variances of grain yield was verified by means of the Hartley test (Ramalho, Ferreira, & Oliveira, 2012). Subsequently, a joint analysis of variance, considering the two environments, was performed for the grain yield means. Topcross mean heritability was estimated for the evaluated characteristics, and the Pearson correlation coefficients among variables were estimated. The means were grouped according to the Scott and Knott (1974) test at 5% probability. Analyses were performed using the statistical program GENES (Cruz, 2013).

Results and discussion

There were significant differences among the genotypes for GY in both environments, and the topcross hybrids vs. checks contrast was significant. A significant effect was also observed for the genotype x environment and (topcross vs. check) x environment interactions (Table 1), indicating that the topcross hybrids (TCHs) exhibited different behavior in response to environmental variation; this can be attributed to genetic differences between the respective S_4 lines that were topcrossed with the same tester.

There were significant differences between the genotypes for CFH, GMY and DMY, as well as for the qualitative and bromatological characteristics of the silage in environment 1 (Table 2). A significant effect was also observed for the topcross hybrids for all of the evaluated silage characteristics, as well as for the TCH vs. C contrast, except for GMY. The only significant effects for the checks were the NFC+EE and RFV. The highest CV among all characteristics was 12,48% (for grain yield), which indicates the good experimental precision.

Table 1. Summary of joint analysis of variance of grain yield (GY, kg ha^{-1}) of 46 maize topcross hybrids (TCH) and checks, evaluated in the 2011/2012 season in two environments in Guarapuava, Paraná State.

SV	DF	Mean Square
Blocks/Environments	4	4898505.47
Genotypes (G)	49	4731500.57*
Topcrosses hybrids (TCH)	45	3718584.98*
Checks (C)	3	10380423.21*
TCH vs C	1	33365934.00*
Environments (E)	1	36569894.21
G x E	49	3621784.30*
TCH x E	45	2922760.39*
C x E	3	5851364.21*
(TCH vs C) x E	1	28389120.48*
Error	196	1879848.26
General Mean		10,987.17
CV (%)		12.48

*Significant at 5% probability according to the F test.

The GY of the TCHs evaluated in environment 1 ranged from 9,442 kg ha^{-1} (TCH 32) to 13,393 kg ha^{-1} (TCH 35) (Table 3). Fifteen TCHs were classified in the most productive group along with the check hybrids Penta, P30F53 and Status, which outperformed the tester hybrid Dow8460. These results emphasize the good potential of the S_4 lines of the TCHs.

Table 2. Summary of the analysis of variance of green mass yield (GMY, kg ha^{-1}), dry matter yield (DMY, kg ha^{-1}), cycle from male flowering to forage harvest (for silage purposes) (CFH, days), neutral detergent fiber (NDF, % in dry matter), acid detergent fiber (ADF, % in dry matter), non-fibrous carbohydrate content plus ether extract (NFC + EE, % in dry matter), total digestible nutrients (TDNs, % in dry matter) and relative feed value of the silage (RFV) of 50 topcross maize hybrids (TCH) and checks evaluated in the 2011/2012 season in Guarapuava, Paraná State.

SV	DF	Mean Square		
		GMY	DMY	CFH
Blocks	1	193210000.00	45800.71	4.84
Genotypes (G)	49	130017739.11*	11661490.40*	25.87*
Topcrosses hybrids (TCH)	45	140570943.76*	12232595.11*	27.77*
Checks (C)	3	9325450.88	2693196.77	0.50
TCH vs C	1	17200394.30	12866659.28*	16.32*
Error	49	27699828.41	1388104.31	0.80
General Mean		71,477.50	20,370.37	42.62
CV (%)		7.36	5.78	2.1

SV	DF	Mean Square				
		NDF	ADF	NFC+EE	TDN	RFV
Blocks	1	0.00028	0.39	4.00	0.19	0.36
Genotypes (G)	49	13.46*	7.22*	13.80*	3.54*	102.30*
Topcrosses hybrids (TCH)	45	13.09*	7.43*	12.94*	3.64*	98.81*
Checks (C)	3	15.66*	0.29	19.46*	0.14	96.46*
TCH vs C	1	23.57*	18.84*	35.31*	9.22*	277.10*
Error	49	3.24	2.99	1.9	1.46	25.16
General Mean		53.47	31.76	37.36	65.61	111.98
CV (%)		3.37	5.44	3.69	1.84	4.48

*Significant at 5% probability according to the F test.

Table 3. Mean values of grain yield (GY), green mass yield (GMY) and dry matter yield (DMY) of the forage, and the cycle from male flowering to forage harvest (for silage purposes) (CFH) of 50 topcross hybrids (TCH) and checks evaluated in the 2011/12 season in Guarapuava, Paraná State.

Genotype	GY (kg ha^{-1})						GMY		DMY		CFH	
	Environment 1			Environment 2			(kg ha^{-1})		(kg ha^{-1})		(days)	
TCH 05	11,881	a	A	11,831	a	A	69,678	b	18,783	c	42	d
TCH 14	10,148	b	A	8,416	b	A	61,607	b	17,795	c	46	c
TCH 28	11,432	b	A	10,125	b	A	62,857	b	17,803	c	41	e
TCH 32	9,442	b	A	10,199	b	A	65,178	b	20,043	c	44	d
TCH 35	13,393	a	A	11,546	a	A	75,535	a	18,580	c	41	e
TCH 42	11,971	a	A	11,266	a	A	77,250	a	20,943	b	39	f
TCH 44	11,954	a	A	11,020	a	A	70,500	b	23,108	a	49	b
TCH 48	11,572	b	A	10,376	b	A	73,928	a	20,779	b	42	d
TCH 51	10,849	b	A	10,417	b	A	75,892	a	18,588	c	38	f
TCH 54	12,624	a	A	9,005	b	B	84,642	a	23,379	a	38	f
TCH 61	11,610	b	A	9,933	b	A	78,571	a	23,589	a	41	e
TCH 65	13,255	a	A	10,341	b	B	87,714	a	26,130	a	43	d
TCH 69	11,213	b	A	10,768	b	A	86,357	a	24,824	a	43	d
TCH 70	10,972	b	A	11,269	a	A	79,107	a	21,009	b	40	e
TCH 71	10,117	b	A	9,815	b	A	67,428	b	17,548	c	38	f
TCH 76	11,607	b	A	10,443	b	A	70,714	b	18,660	c	40	e
TCH 77	11,062	b	A	10,301	b	A	52,535	c	15,621	d	44	d
TCH 84	11,029	b	A	9,836	b	A	67,285	b	21,249	b	46	c
TCH 97	10,795	b	A	10,019	b	A	69,178	b	22,572	a	46	c
TCH 101	10,976	b	A	13,043	a	A	70,000	b	23,374	a	47	c
TCH 105	10,521	b	A	10,026	b	A	70,178	b	18,486	c	41	e
TCH 109	12,192	a	A	11,153	a	A	69,820	b	19,577	c	42	d
TCH 112	10,496	b	A	11,400	a	A	79,928	a	21,796	b	43	d
TCH 114	9,636	b	A	10,790	b	A	73,857	a	20,881	b	41	e
TCH 115	10,721	b	A	10,391	b	A	65,750	b	21,394	b	44	d
TCH 118	12,077	a	A	10,356	b	A	84,464	a	23,748	a	56	a
TCH 119	13,364	a	A	12,839	a	A	77,678	a	22,021	b	40	e
TCH 121	10,003	b	A	11,346	a	A	71,785	b	19,654	c	40	e
TCH 124	11,617	b	A	10,930	a	A	61,428	b	15,881	d	43	d
TCH 132	10,257	b	A	11,727	a	A	74,928	a	22,753	a	47	c
TCH 140	11,877	a	A	8,704	b	B	62,875	b	19,952	c	50	b
TCH 148	11,278	b	A	11,761	a	A	82,142	a	21,042	b	39	f
TCH 151	10,382	b	A	10,918	a	A	78,428	a	20,626	b	42	d
TCH 152	10,914	b	A	8,992	b	A	65,535	b	18,530	c	40	e
TCH 154	9,901	b	A	10,036	b	A	68,250	b	19,654	c	44	d
TCH 156	13,260	a	A	10,054	b	B	72,964	a	20,766	b	49	b
TCH 165	9,751	b	A	9,518	b	A	77,500	a	19,839	c	39	f
TCH 168	10,287	b	A	10,613	b	A	71,928	b	19,898	c	43	d
TCH 169	10,194	b	A	8,998	b	A	67,142	b	18,856	c	41	e
TCH 170	10,939	b	A	11,357	a	A	52,607	c	14,749	d	40	e
TCH 181	10,987	b	A	9,778	b	A	78,392	a	19,820	c	41	e
TCH 182	10,775	b	A	10,036	b	A	48,767	c	15,053	d	47	c
TCH 183	12,601	a	A	10,959	a	A	70,089	b	19,162	c	39	f
TCH 185	10,538	b	B	13,428	a	A	68,678	b	21,800	b	48	b
TCH 190	10,121	b	A	10,647	b	A	70,178	b	22,465	a	40	e
TCH 193	10,160	b	A	12,246	a	A	71,071	b	19,368	c	41	e
Means	11,147			10,630			71,355		20,264		43	
Checks												
Dow8460 (T)	11,549	b	A	9,728	b	A	70,642	b	21,774	b	41	e
P30F53	13,235	a	A	10,740	b	B	74,642	a	22,878	a	41	e
Penta	14,821	a	A	9,184	b	B	71,428	b	20,058	c	41	e
Status	14,435	a	A	13,248	a	A	74,821	a	21,635	b	42	d

(T) = Tester; Means followed by the same lower case letter within a column and capital letter within a line belong to the same group according to the Scott-Knott test at 5% probability.

In environment 2, GY ranged from 8,416 kg ha^{-1} (TCH 14) to 13,428 kg ha^{-1} (TCH 185) (Table 3). TCH 185 exceeded approximately 20% of the average GY of the commercial hybrids (10,725 kg ha^{-1}) and belonged to the group containing eighteen TCHs that were more productive than the check Status, according to the Scott-Knott test. These TCHs had GY values that were higher than those of the checks P30F53 and Penta and the tester Dow8460.

The grain yield values obtained in this study are in agreement with those presented by Ferreira et al. (2009), who identified topcross hybrids of S_3 progenies with yields better than those of commercial hybrids used as checks. Oliboni et al. (2013) evaluated a diallel involving a set of commercial hybrids and found positive estimates for general combining ability of P30F53 for husked ear yield, indicating an average increase in the gene contribution to grain yield in the crosses. These authors also reported a high husked ear yield for the cross P30F53 x Penta, which were used as parentals in the generation of the base population to obtain the S_4 lines evaluated in topcrosses in the present study.

The topcrosses hybrids TCH 05, TCH 35, TCH 42, TCH 44, TCH 109, TCH 119, and TCH 183, and the commercial hybrid Status ranked among the most productive genotypes in both environments, and TCH 185 was more productive in environment 2 (Table 3).

The GMY ranged from 48,767 kg ha^{-1} (TCH 182) to 87,714 kg ha^{-1} (TCH 65) (Table 3). These values are higher than those reported by Assis et al. (2014) in an evaluation of the agronomic characteristics of corn hybrids during ensiling. Nineteen TCHs did not differ statistically from the check hybrids P30F53 and Status, and they were superior to the commercial hybrids Penta and Dow8460 (tester). These results indicate the potential for selection among the topcrosses hybrids with respect to the GMY.

The average DMY ranged from 14,749 kg ha^{-1} (TCH 170) to 26,130 kg ha^{-1} (TCH 65) (Table 3). Ten TCHs were classified in the group with the highest dry mass yield along with the hybrid P30F53, surpassing the hybrid tester Dow8460, the parental Penta and the commercial check Status, and providing evidence of the superiority of the S_4 line as parentals of topcross hybrids with respect to the DMY. TCH 44, TCH 54, TCH 61, TCH 65, TCH 69, TCH 101 and TCH 118 stood out for having a DMY 6 to 17% higher than the average value of the four commercial hybrids (21,586 kg ha^{-1}).

The DMY (Table 3) were higher than those reported by Rosa et al. (2004), who studied the behavior of maize hybrids in the Rio Grande do Sul state, and by Assis et al. (2014), who evaluated the agronomic characteristics of corn hybrids during ensiling in São Paulo State. However, the DMY values were similar to the value presented by Jaremtchuk et al. (2005), who reported an average of 20,730 kg ha^{-1} in an evaluation of the agronomic and bromatological parameters of 20 maize hybrids in eastern Paraná State.

Almost all TCHs with high GMY values were also those that had the highest DMY values, indicating that, a priori, the majority of the S_4 partly inbred lines are potentially useful for breeding programs for forage purposes, except for the S_4 lines of TCH 77, TCH 124, TCH 170 and TCH 182, for which the DMY values were less than 18,000 kg ha^{-1} and therefore considered unsatisfactory as suggested by Neumann (2011).

Evangelista and Lima (2002) recommend harvesting forage in the range of 30-35% dry matter of plants, during the milk-line stage when the consistency of the grains ranges between the soft and hard dough stages. In environment 1, the CFH (for silage purposes) was variable (Table 3). The ideal CFH based on the 75% milk-line stage ranged from 38 to 56 days (Table 3) due to genetic differences between the S_4 parental lines of the TCHs.

The pattern of physiological maturity of each genotype influences the accumulation of dry matter of a maize plant, which depends on the environmental conditions (Zopollatto et al., 2009). Inbred lines with different maturity cycles are important in breeding programs to obtain hybrids, as these can be employed in a management plan that enables the scaling of the forage harvest, maintaining the ideal milk-line for silage over the crop season period.

The NDF content ranged from 44.85% (TCH 76) to 58.45% (TCH 51) (Table 4); these values are close to those reported by Gralak et al. (2014). TCH 76 and the commercial hybrid Penta were the only ones classified in the group with lower NDF according to the Scott-Knott test. The intermediate group was composed of 12 topcrosses with lower values than the check hybrids, including the tester Dow8460. The values observed by Pedroso, Ezequiel, Osuna, Santos (2006) were higher than these, and these authors reported means above 58% for NDF. According to Neumann (2011), NDF values below 53% are suitable for good quality silage, which was the case for 16 topcross hybrids among the evaluated genotypes.

The ADF consists almost entirely of lignin and cellulose and is the least digestible portion of the cell wall of forage (Silva & Queiroz, 2002). The lower the ADF value, the greater the energy value of the silage (Fancelli & Dourado Neto, 2004). The ADF values ranged from 28.28% (TCH 76) to 37.06% (TCH 61) (Table 4). In an evaluation of the bromatological characteristics of silage, Silva et al. (2003) reported similar values for ADF, i.e., between 30.5 and 37.2%, for interpopulational maize hybrids in Jaboticabal, São Paulo State. All of the topcrosses hybrids evaluated had favorable ADF values for the production of silage according to Neumann (2011), implying that the partly inbred S_4 lines of these genotypes have the potential to be used to obtain hybrids suitable for animal feed.

The non-fibrous carbohydrate concentration is related to the content of sugars present in plant cells that are rapidly and completely fermented in the rumen (Saliba, Rodriguez, & Gonçalves, 2009). The higher the non-fibrous carbohydrate concentration, the higher the nutritional value of the silage (Tres et al., 2014). According to Neumann (2011), non-fibrous carbohydrate levels above 33% of dry matter are considered good for silage. The estimated values of the non-fibrous carbohydrates plus ether extract (NFC + EE) ranged from 33 to 47% (Table 4), and TCH 76 presented the highest NFC + EE content among the evaluated genotypes.

Table 4. Mean values of neutral detergent fiber (NDF), acid detergent fiber (ADF), non-fibrous carbohydrates plus ether extract (NFC + EE), and total digestible nutrients (TDNs), expressed as a percentage of dry matter, and the relative feed value (RFV) of the silage of 50 maize topcross hybrids (TCHs) and checks, evaluated in the 2011/12 season in Guarapuava, Paraná State.

Genotype	NDF		ADF		NFC+EE		TDN		RFV	
	--------------------(% in dry matter)--------------------									
TCH 5	57.19	a	32.47	a	34.0	e	65.12	b	103.5	c
TCH 14	49.07	b	29.54	b	41.5	c	67.17	a	125.5	b
TCH 28	56.57	a	31.83	b	35.0	e	65.56	a	105.5	c
TCH 32	55.98	a	31.52	b	34.5	e	65.78	a	107.0	c
TCH 35	52.85	a	32.54	a	38.0	d	65.07	b	112.0	c
TCH 42	54.24	a	30.12	b	36.5	d	66.76	a	112.0	c
TCH 44	51.94	b	31.88	b	39.0	c	65.53	a	114.5	c
TCH 48	54.77	a	31.35	b	36.0	d	65.90	a	110.0	c
TCH 51	58.45	a	33.11	a	33.0	e	64.67	b	100.5	c
TCH 54	53.77	a	36.53	a	37.5	d	62.27	b	104.5	c
TCH 61	53.30	a	37.06	a	37.5	d	61.90	b	104.5	c
TCH 65	52.97	a	34.45	a	38.0	d	63.73	b	109.0	c
TCH 69	53.00	a	30.99	b	37.5	d	66.15	a	113.5	c
TCH 70	53.16	a	32.54	a	37.5	d	65.07	b	111.5	c
TCH 71	52.37	b	32.81	a	38.5	c	64.87	b	112.5	c
TCH 76	44.85	c	28.28	b	47.0	a	68.05	a	138.5	a
TCH 77	57.90	a	31.28	b	32.5	e	65.95	a	103.5	c
TCH 84	54.71	a	29.42	b	36.5	d	67.25	a	112.5	c
TCH 97	57.52	a	29.78	b	33.5	e	67.00	a	106.0	c
TCH 101	57.20	a	29.47	b	34.0	e	67.22	a	107.5	c
TCH 105	56.12	a	34.92	a	35.0	e	63.40	b	102.5	c
TCH 109	50.74	b	30.92	b	40.0	c	66.20	a	119.0	b
TCH 112	49.71	b	28.66	b	40.5	c	67.78	a	124.5	b
TCH 114	54.89	a	33.25	a	35.5	e	64.57	b	106.5	c
TCH 115	52.23	b	31.21	b	39.0	c	66.00	a	115.5	c
TCH 118	55.66	a	32.10	b	35.0	e	65.38	a	107.0	c
TCH 119	54.66	a	30.64	b	36.0	d	66.40	a	111.0	c
TCH 121	53.30	a	32.87	a	37.0	d	64.84	b	110.5	c
TCH 124	53.69	a	34.58	a	37.0	d	63.63	b	107.5	c
TCH 132	54.18	a	33.12	a	36.0	d	64.66	b	108.5	c
TCH 140	51.13	b	29.96	b	40.0	c	66.88	a	119.5	b
TCH 148	53.07	a	33.62	a	37.5	d	64.31	b	110.0	c
TCH 151	52.10	b	30.78	b	38.5	c	66.30	a	116.0	c
TCH 152	52.94	a	31.59	b	37.5	d	65.73	a	113.0	c
TCH 154	51.32	b	30.59	b	39.5	c	66.43	a	118.0	b
TCH 156	54.79	a	32.04	b	36.0	d	65.42	a	108.5	c
TCH 165	55.39	a	33.47	a	35.5	e	64.41	b	105.5	c
TCH 168	55.03	a	33.32	a	36.0	d	64.52	b	106.5	c
TCH 169	51.32	b	32.02	b	39.0	c	65.43	a	116.0	c
TCH 170	55.08	a	29.23	b	35.5	e	67.39	a	111.5	c
TCH 181	53.72	a	33.01	a	36.5	d	64.73	b	109.5	c
TCH 182	54.94	a	31.80	b	36.5	d	65.59	a	108.5 TCH	c
TCH 183	50.62	b	29.65	b	39.5	c	67.09	a	121.0	b
TCH 185	54.27	a	32.01	b	37.0	d	65.43	a	109.5	c
TCH 190	53.61	a	34.08	a	37.0	d	63.99	b	108.0	c
TCH 193	50.08	b	30.34	b	40.5	c	66.61	a	121.0	b
Means	53.61		31.88		37.2		65.52		111.5	
Checks										
Dow8460 (T)	52.81	a	30.39	b	38.5	c	66.57	a	115.0	c
P30F53	53.60	a	29.91	b	37.5	d	66.91	a	114.0	c
Penta	47.66	c	30.07	b	44.0	b	66.79	a	128.0	b
Status	53.24	a	30.77	b	37.5	d	66.30	a	113.5	c

(T) = Tester; Means followed by the same lower case letter in the column and capitalized in line belong to the same group according to the Scott-Knott test at 5% probability.

The topcrosses hybrids TCH 76, TCH 14, TCH 109, TCH 112, TCH 140, TCH 154 and TCH 183 composed the intermediate group, with high values of NFC + EE, and these were also the hybrids that showed low levels of NDF and ADF, and the highest RFV (Table 4).

The TDN estimates are related to the energy value of the silage. Twenty-eight topcross hybrids were classified in the top group (Table 4) and did not differ from the parental hybrids, tester or check Status; the TDN values (> 65%) of these hybrids were classified as suitable according to Neumann (2011). The estimated averages of the total digestible nutrients (TDNs) were similar to those obtained by Mello et al. (2005), which ranged from 59 to 71% in an evaluation of commercial maize hybrids for silage in Rio Grande do Sul State, and those reported by Jaremtchuk et al. (2005), which ranged from 63 to 69% in an evaluation of 20 commercial maize hybrids for silage in the eastern region of Paraná State.

The RFV combines consumption (estimated according to the NDF) with food digestibility (represented by the ADF). According to

Neumann (2011), estimates of RFV above 115 are acceptable for good quality silage. The topcrosses TCH 14, TCH 76, TCH 109, TCH 112, TCH 140, TCH 154, TCH 183 and TCH 193 and the parental Penta formed the group with the highest RFV values and were also those with lower NDF and ADF values (Table 4). This group outperformed the parental hybrid P30F53, the tester Dow8460 and the check hybrid Status, which had higher NDF and ADF values and a low RFV value. These results can be attributed to the favorable alleles of the S_4 lines of these TCHs because the tester was common to all genotypes.

The heritability estimated for GY (0.21) was the lowest among all evaluated characteristics (Table 5). The highest estimates were observed for CFH, DMY and NFC+EE, i.e., 0.87, 0.89 and 0.86, respectively, but other bromatological characteristics also had heritability means above 0.75, except for ADF and TDN. Therefore, these results show that most of the existing variance in the bromatological traits is of a genetic nature, which favors the selection process for these characteristics by increasing the likelihood of genetic gain.

Table 5. Estimates of heritability coefficients (h^2) and correlation among grain yield (GY), green mass yield (GMY), dry matter yield (DMY), the cycle from male flowering to forage harvest (for silage purposes) (CFH), neutral detergent fiber (NDF), acid detergent fiber (ADF), non-fibrous carbohydrate content plus ether extract (NFC+EE), total digestible nutrients (TDNs) and relative feed value (RFV) of the silage of 46 top cross hybrids of maize evaluated in the 2011/2012 season in Guarapuava, Paraná State.

	GY	GMY	DMY	CFH	NDF	ADF	NFC+EE	TDN	RFV
GY	-	0.28*	0.27*	0.01	-0.01	-0.13	0.28	0.13	0.54
GMY	-	-	0.76*	-0.14	-0.08	0.30*	0.06	-0.30*	-0.05
DMY	-	-	-	0.21	-0.01	0.14	0.00	-0.14	-0.06
CFH	-	-	-	-	0.12	-0.18	-0.11	0.18	-0.03
NDF	-	-	-	-	-	0.33*	-0.98*	-0.33*	-0.92*
ADF	-	-	-	-	-	-	-0.33*	-1,0*	-0.65*
NFC+EE	-	-	-	-	-	-	-	0.33*	0.92*
TDN	-	-	-	-	-	-	-	-	0.65*
h^2	0.21	0.79	0.89	0.87	0.75	0.58	0.86	0.59	0.75

*Significant at 5% probability according to the t test.

In an evaluation of nine open-pollinated maize genotypes, Idris and Abuali (2011) obtained a heritability value of 0.21 for grain yield in one of the two seasons evaluated. This value is similar to the heritability obtained in the current experiment.

With respect to the correlation among the characteristics (Table 5), a significant negative correlation was observed between GMY and TDN (-0.30), NDF and NFC+EE (-0.98), NDF and TDN (-0.33), NDF and RFV (-0.92), ADF and NFC+EE (-0.33), ADF and TDN (-1.00), and ADF and RFV (-0.65). The characteristics that showed significant positive correlations were GY and GMY (0.28), GY and DMY (0.27), GMY and DMY (0.76), GMY and ADF (0.30), NDF and ADF (0.33), NFC+EE and TDN (0.33), NFC+EE and RFV (0.92) and TDN and RFV (0.65).

Santos et al. (2010) also observed a high significant correlation between GMY and DMY (0.92) ($p < 0.05$), similar to Mendes et al. (2008), who reported a correlation of 0.95 ($p < 0.05$). The latter authors observed a higher correlation than that presented in this work for NDF and ADF (0.56), GY and GMY (0.81), GY and DMY (0.75) ($p < 0.05$).

The significant correlation between GY and GMY, GY and DMY, NDF and ADF deserves to be highlighted because of the low heritability of the GY and ADF characteristics, assuming that these can be selected through inference based on other characteristics such as GMY, DMY and ADF, which showed high heritability in this experiment.

Conclusion

The tester, hybrid Dow8460, was efficient to discriminate the relative performance of the S_4 lines in the topcrosses.

It was possible to identify S_4 maize lines with superior performance that should be retained in the inbreeding process; some of these lines were the most promising for grain yield whereas others showed the best potential for silage production.

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