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Assessment of agronomic performance and prediction of genetic gains through selection indices in silage corn

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Abstract

During the dry season, the production of pastures is decreased, making farmers necessary to use corn silage as roughage source. Maize is increasingly recommended as the most important silage crop due to their qualitative and quantitative traits on top of the great acceptance for most animals. This work aimed to evaluate, through selection indices, the agronomic performance and prediction of genetic gains in corn hybrids for silage production. Eight topcross hybrids and seven controls were assessed in randomized blocks with six replications in two environments, in the municipalities of Campos dos Goytacazes and Itaocara - RJ, respectively, in the 2015/2016 agricultural year. The following agronomic traits were assessed: plant height (PH), height of first ear insertion (TH), stem diameter (CD), number of ears (NT), yield of ear with straw and ready for silage (TPS); yield of ear without straw and ready for silage (TPWS); yield of grain ready for silage (GY); ratio of grains in the fresh weight (GFM) and fresh weight yield (FMY). The selection indices of Smith & Hazel, Willians, Pesek & Baker and Mulamba & Mock were used for gain prediction. The results showed that Mulamba & Mock provided the highest predictive values in the estimation of gains for the selection of hybrids. The topcross hybrids UENF-2205, UENF-2208, UENF-2209 and UENF-2210 presented the best performance and indicated high potential of TPWS, GY and GFM for silage production in the Northern and Northwestern Rio de Janeiro state.

Keywords: Hybrids, Topcrosses, Tester, Production, *Zea mays* L.
Abbreviations: PH_plant height; TH_ear height; CD_stem diameter; NT_total number of harvested ears; TPS_yield of ear with straw ready for silage; TPWS_yield of ear without straw ready for silage; GY_yield of grains ready for silage; GFM_proportion of grains in fresh weight; FMY_fresh weight yield; CV_e_coefficient of experimental variation; CV_g_coefficient of genetic variation; I_v_variation index; H^2_genotypic determination coefficient and $\hat{r}gg$_ accuracy; HT_topcross hybrids; TDE_dent control; TSD_semi-dent control; TDU_flint control; G_genotype; A_environment.

Introduction

The exploitation of milk and beef cattle requires high herd productivity throughout the year. In Brazil, it is necessary to provide food supplementation, mainly in autumn and winter, due to the seasonality of forage production, when the use of roughage is critical (Gomes et al., 2004). Corn plays an important role in forage crops used for supplementation, due to its high fresh weight yield per hectare, besides its good nutritional qualities which increase production and the nutritive value of silage (Melo et al., 1999).

Corn silage is a widely used food, but some erroneous concepts are still observed in the selection of cultivars, when the quality of the product is not prioritized (Villela, 2001). The best hybrids of corn intended for grain production are usually the same as those recommended for silage production. Brazilian maize breeding programs are focused on the production of hybrids for grain production (Gomes et al., 2004). Thus, the lack of information about agronomic response, productivity and nutritional value has become an obstacle to the selection of corn hybrids for silage production. Therefore, the agronomic characterization of the genetic material is fundamental for obtaining silage (Rosa et al., 2004).

Heterotic groups has been defined as a collection of germplasm that, when crossed with germplasm from another group, tends to exhibit higher levels of heterosis than when crossed with members of its own group (Lee, 1995). In Brazil, one of the most exploited heterotic patterns in maize breeding program has been the cross between genotypes of the dentate type endosperm with hard type endosperm genotypes. In the case of corn, there are two heterotic groups: the so-called "Dent" and the "Flint". Most hybrids come from heterotic intergroup crossover.

Recent evidence indicates that rumen digestibility of corn starch varies according to genetic differences among the maize hybrids. According to Rossi et al. (2016), the group of dent hybrids exhibited better ruminal digestibility of the grains associated with lower vitreousness versus the group of flint hybrids. Cruz et al. (2004) considers that the selection of genotypes should be based on several favorable agronomic traits, gand pursue the simultaneous breeding of such traits. Therefore, selection indices are very useful tools in plant breeding, since they efficiently allow for the selection of superior genotypes. The most commonly used indices include Smith (1936) & Hazel (1943), Willians (1962), Pesek & Baker (1969) and Mulamba & Mock (1978).

These indices constitute a multivariate technique that gathers information related to several traits of agronomic interest and the genetic properties of the population under study. Selection indices allow for the creation of a numerical value that works as an additional and theoretical character, resulting from the combination of certain traits interesting for simultaneous selection (Cruz et al., 2004).

The Smith index (1936) was the first to be used in plant breeding as a criterion for the simultaneous selection of two or more correlated characteristics. Hazel (1943) then adapted this methodology for animal breeding. According to both authors, the economic values relative to each trait and the genotypic and phenotypic covariates in each pair of traits are required to use the selection index. Willians (1962) proposed the base index, which dispenses with the estimation of phenotypic and genotypic variances and covariates. Thus, this index is established by the linear combination of the mean phenotypic values of the characters weighted by their respective economic weights (Cruz et al., 2004).

Pesek & Baker (1969) suggested the use of "desired genetic gains". For this proposal, the mean of genotypes and matrices of variance and genotypic and phenotypic covariance are required. In this way, it is possible to calculate the coefficients of the indices, without designating economic weights that resulted in a maximum gain for each characteristic. This is according to the relative importance assumed by the breeder in the specification of the desired gain, subject to the constraints imposed by the phenotypic and genotypic constitution of the population. Mulamba & Mock (1978) proposed the index based on the sum of ranks. This index ranks the genotypes, initially for each trait, by assigning higher absolute numbers to genotypes with superior performance. Once classified, the values assigned to each trait are summed, obtaining the ‘sum of ranks’, which indicates the classification of genotypes (Cruz et al., 2004).

The selection indices have often been used by the corn improvement program. Tardin et al. (2007) used the Smith & Hazel selection index in the selection of complete sib families of maize, obtaining satisfactory estimates of gains for most of the characteristics evaluated. Gabriel et al. (2006) also selected higher families in the 10th cycle of recurrent selection, using the Smith & Hazel index. Berilli et al. (2013) also selected upper full-sib families based on the Mulamba & Mock índex. According to Entringer et al. (2016), the selection indices of Mulamba & Mock was the most suitable for the selection of half-sib families in super sweet corn.

The corn silage market has strong growth potential and the Brazilian livestock is totally dependent on this additional source of roughages. It is also worth mentioning that Brazil has no breeding programs specifically targeting forage, or specific varieties to meet this demand, which explains the significance of the present research.

Therefore, this work aimed to predict genetic gains through selection indices in corn hybrids for silage production and assess their agronomic performance.

Results and Discussion

Analysis of variance and genetic parameters

Significant effects ($p \leq 0.01$) were observed for all studied traits, indicating genetic variability among the genotypes. The effects of the genotype x environment interaction were significant only for GFM and FMY. Significant interaction indicates that the genotype responses varied at different environments (Table 2). The analysis of the contrasts involving the topcross hybrids *vs.* controls showed significant differences only for PH, TH, CD and FMY.

For the contrast between topcross hybrids and hard controls, significant differences were evidenced for all analyzed variables, revealing that the heterotic groups differ from each other (Table 2). The results for the average topcross hybrids were satisfactory. They demonstrated high productive potential for the Northern and Northwestern Rio de Janeiro. The averages of the controls were lower for all variables analyzed (Table 2).

According to the classification of Scapim et al. (1995), the CV_e rates of the traits evaluated in the present work were classified from low to high. Note that the coefficients of variation ranged from 5.12% for AP to 26.64% for GY (Table 2). These coefficients of variation showed acceptable experimental precision for all traits assessed, which corroborates the estimates and results obtained in this work.

Selection accuracy is useful for simultaneous identification of the environmental and genetic variation at the 0 to 100% scale. According to Ramalho et al. (2012), values above 70% are desirable in genotype evaluation experiments. In the present study, all values were above 0.92, which probably indicates successful selection (Table 2). Considering the above, it is evident that in this study, the environmental effects related to the test environments did not prevail over the genetic variability of the genotypes nor affected it. Therefore, it is possible to conclude that selection for silage can be successfully carried out for the different variables of corn.

Estimates of genetic gains by selection index

Table 3 presents the estimates of the percentage gains predicted by the Pesek & Baker, Smith & Hazel, Mulamba & Mock and Willians selection indices, using weights attributed per trial. The selection was performed for the traits PH, TH, CD, NT, TPS, TPWS, GY, GFM and FMY. The results obtained through selection indices revealed that the Mulamba & Mock index provided the best estimates of gains, because it was possible to obtain average gains for all evaluated traits.

Table 1. Description of the 8 topcross hybrids, 7 controls and tester used in the experiments concerning grain type and origin. Campos dos Goytacazes and Itaocara - RJ, in the crop year 2015/2016.

Identification	Genotype	Grain type	Origin
1	UENF-2205 *	Dent	UENF
2	UENF-2198*	Dent	UENF
3	UENF-2207*	Dent	UENF
4	UENF-2208*	Dent	UENF
5	UENF-2209*	Dent	UENF
6	UENF-2210*	Dent	UENF
7	UENF-2202*	Dent	UENF
8	UENF-2191*	Dent	UENF
9	AG 1051**	Dent	Commercial
10	UENF 506-11**	Semi-dent	UENF
11	Composto Flint Normal**	Flint	UENF
12	Sol da Manhã**	Flint	UENF
13	Saracura**	Flint	UENF
14	Cateto Sete Lagoas**	Flint	UENF
15	Cimmyt 12**	Flint	UENF
-	Piranão 12***	Dent	UENF

*Topcross hybrids; ** Controls; *** Tester

Table 2. Summary of the joint analysis variance of nine traits assessed in corn hybrids for silage. Campos dos Goytacazes and Itaocara, RJ, agricultural year 2015/2016.

		Mean squares								
FV	GL	PH	TH	CD	NT	TPS	TPWS	GY	GFM	FMY
Block/Environment	10	0.127	0.032	15.794	44.232	12704427.18	5124740.55	6174884.58	49.417	218208646.97
Genotype (G)	14	0.872**	0.534**	28.096**	227.160**	58630438.74**	41075268.75**	45741692.89**	253.888**	694328908.77**
Environment (A)	1	1.210**	0.500**	0.103 ^{ns}	849.338**	520829190.13**	75886288.2**	32281711.02**	27.323^{ns}	1717854693.88**
G x A	14	0.018^{ns}	0.010^{ns}	5.057^{ns}	29.731^{ns}	6361321.04^{ns}	3220131.2^{ns}	4602091.02^{ns}	43.031*	57082567.51*
HT *vs* TDE	1	0.524**	0.443**	13.206 ^{ns}	633.796**	1026784.6 ^{ns}	9328183.6 ^{ns}	37311487.5**	543.57**	214018565 ^{ns}
HT *vs* TSD	1	1.014**	0.00004 ^{ns}	5.577 ^{ns}	317.796**	9210519.5 ^{ns}	4952687.8 ^{ns}	132536.3 ^{ns}	0.4727 ^{ns}	9948083 ^{ns}
HT *vs* TDU	1	7.271**	1.962**	207.633**	267.510**	445260511.8**	284595950.3**	334586508.8**	466.85**	5898419077**
HT *vs* Controls	1	3.423**	0.674**	27.511*	88.132 ^{ns}	29389376.6 ^{ns}	4854050.8 ^{ns}	5052244.5 ^{ns}	41.042 ^{ns}	1180291284**
Error	140	0.014	0.008	3.859	18.786	3795018.77	2145899.7	2757549.21	19.601	25944711.63
Average hybrids	-	2.50	1.62	23.52	29.70	12,555	8,526	7,118	17.68	41,609
Average controls	-	2.10	1.43	21.77	27.46	10,163	6,774	5,219	16.13	31,803
CV_e (%)	-	5.12	5.84	8.65	15.12	17.03	19.00	26.64	26.10	13.75
CV_g (%)	-	11.57	13.67	6.26	14.53	18.68	23.36	30.36	26.05	20.15
I_v	-	2.26	2.34	0.72	0.96	1.09	1.22	1.13	0.99	1.46
H^2	-	98.39	98.50	86.26	91.73	93.52	94.77	93.97	92.27	96.26
$\hat{r}gg$	-	0.99	0.99	0.92	0.95	0.96	0.97	0.96	0.96	0.98

PH: plant height (m); TH: ear height (m); CD: stem diameter (mm); NT: total number of harvested ears; TPS: yield of ear with straw ready for silage (kg ha^{-1}); TPWS: yield of ear without straw ready for silage (kg ha^{-1}); GY: yield of grains ready for silage (kg ha^{-1}); GFM: proportion of grains in fresh weight (%) and FMY: fresh weight yield (kg ha^{-1}); ^{ns}: Non-significant by the F test; **: Significant ($P < 0.01$) by the F test; *: Significant ($P < 0.05$) by the F test; CV_e: coefficient of experimental variation; CV_g: coefficient of genetic variation; I_v: variation index; H^2: genotypic determination coefficient and $\hat{r}gg$: accuracy; HT: topcross hybrids; TDE: dent control; TSD: semi-dent control; TDU: flint control.

Table 3. Estimate of the percentage gains based on the selection differential per simultaneous selection, in nine traits in corn genotypes for silage, Campos dos Goytacazes and Itaocara - RJ, agricultural year of 2015/2016.

	Selection Indices			
Traits[1]	Pesek & Baker	Smith & Hazel	Mulamba & Mock	Willians
PH	-1.01	8.53	5.99	8.53
TH	-1.67	9.87	6.69	9.87
CD	-1.02	3.59	2.32	3.59
NT	-1.74	6.79	6.79	6.79
TPS	3.47	17.87	13.04	17.87
TPWS	5.58	14.34	17.55	14.34
GY	0.45	11.22	24.09	11.22
GFM	-2.75	-8.51	13.12	-8.51
FMY	4.49	22.13	12.58	22.13

PH: plant height (m); TH: ear height (m); CD: stem diameter (mm); NT: total number of harvested ears; TPS: yield of ear with straw ready for silage (kg ha^{-1}); TPWS: yield of ear without straw ready for silage (kg ha^{-1}); GY: yield of grains ready for silage (kg ha^{-1}); GFM: proportion of grains in fresh weight (%) and FMY: fresh weight yield (kg ha^{-1}).

Table 4. Ranking and average of nine traits evaluated in five hybrids of corn for silage, selected by the Mulamba & Mock index. Campos dos Goytacazes and Itaocara, RJ, agricultural year of 2015/2016.

		Traits average				
Ranking	Genotype	PH	TH	CD	NT	TPS
1	UENF-2210	2.68	1.66	22.86	28.67	14,489
2	UENF-506-11	2.19	1.63	24.25	35.17	13,485
3	UENF-2209	2.65	1.77	24.20	28.58	14,298
4	UENF-2202	2.49	1.63	21.64	28.33	11,671
5	UENF-2191	2.29	1.51	23.65	33.17	11,228
		Traits average				
Ranking	Genotype	TPWS	GY	GFM	FMY	
1	UENF-2210	9,963	8,283	18.85	44,480	-
2	UENF-506-11	9,208	7,007	17.48	40,644	-
3	UENF-2209	9,745	8,135	16.23	50,083	-
4	UENF-2202	8,969	8,417	23.89	37,231	-
5	UENF-2191	7,797	7,309	20.44	36,923	-

PH: plant height (m); TH: ear height (m); CD: stem diameter (mm); NT: total number of harvested ears; TPS: yield of ear with straw ready for silage (kg ha^{-1}); TPWS: yield of ear without straw ready for silage (kg ha^{-1}); GY: yield of grains ready for silage (kg ha^{-1}); GFM: proportion of grains in fresh weight (%) and FMY: fresh weight yield (kg ha^{-1}).

Table 5. Scott-Knott's clustering test for seven traits evaluated in hybrids of corn for silage. Campos dos Goytacazes and Itaocara, RJ, agricultural year of 2015/2016.

	Traits average						
Genotype	PH	TH	CD	NT	TPS	TPWS	GY
UENF-2205	2.28 d	1.40 c	24.09 a	27.58 b	12,663 b	8,081 b	5,315 c
UENF-2198	2.54 c	1.62 e	23.35 b	30.25 a	10,960 c	8,317 b	7,007 b
UENF-2207	2.29 d	1.42 c	25.55 a	27.17 b	11,944 b	7,962 b	6,340 b
UENF-2208	2.81 a	1.98 a	22.87 b	33.92 a	13,189 a	7,377 b	6,140 b
UENF-2209	2.65 b	1.77 b	24.20 a	28.58 b	14,297 a	9,745 a	8,135 a
UENF-2210	2.68 b	1.66 e	22.86 b	28.67 b	14,489 a	9,963 a	8,283 a
UENF-2202	2.49 c	1.63 e	21.64 c	28.33 b	11,671 b	8,969 a	8,417 a
UENF-2191	2.29 d	1.51 d	23.65 b	33.17 a	11,228 b	7,797 b	7,309 b
AG 1051	2.28 d	1.42 c	22.41 c	22.00 c	12,245 b	9,462 a	8,988 a
UENF 506-11	2.19 d	1.63 e	24.25 a	35.17 a	13,484 a	9,208 a	7,007 b
Composto Flint Normal	2.01 e	1.43 c	22.00 c	32.00 a	9,994 c	6,677 c	4,310 c
Sol da Manhã	1.90 f	1.11 g	20.00 d	21.42 c	8,346 d	5,321 d	3,690 d
Saracura	2.05 e	1.31 f	20.27 d	24.08 c	10,692 c	7,340 b	5,131 c
Cateto Sete Lagoas	2.33 d	1.70 b	21.85 c	24.33 c	6,237 e	2,950 e	2,001 e
Cimmyt 12	2.00 e	1.42 c	21.64 c	33.25 a	10,144 c	6,462 c	5,407 c

PH: plant height (m); TH: ear height (m); CD: stem diameter (mm); NT: total number of harvested ears; TPS: yield of ear with straw ready for silage (kg ha^{-1}); TPWS: yield of ear without straw ready for silage (kg ha^{-1}); GY: yield of grains ready for silage (kg ha^{-1}); GFM: proportion of grains in fresh weight (%) and FMY: fresh weight yield (kg ha^{-1}). Average followed by the same letter, in the same column, did not differ statistically from each other by the Scott-Knott clustering test P≤0.05.

Table 6. Scott-Knott clustering test for GFM and FMY in hybrids of corn for silage, splitting of the Genotype × Location interaction. Campos dos Goytacazes and Itaocara, RJ, in the agricultural year of 2015/2016.

	Traits average			
	Location 1	Location 2	Location 1	Location 2
Genotype	GFM	GFM	FMY	FMY
UENF-2205	13.67 b A	10.81 c A	44,791 b A	42,249 a A
UENF-2198	21.88 a A	21.28 a A	38,430 b A	26,839 c B
UENF-2207	17.45 a A	14.69 b A	45,065 b A	32,937 b B
UENF-2208	12,65 b A	11.77 c A	54,580 a A	43,433 a B
UENF-2209	16.22 a A	16.24 b A	53,751 a A	46,416 a B
UENF-2210	16.91 a A	20.79 a A	46,224 b A	42,736 a A
UENF-2202	20.67 a B	27.11 d A	43,290 b A	31,173 b B
UENF-2191	16.64 a B	24.24 a A	42,131 b A	31,715 b B
AG 1051	21.22 a B	28.43 d A	39,885 b A	34,376 b A
UENF 506-11	17.56 a A	17.40 b A	41,357 b A	39,932 a A
Composto Flint Normal	16.33 a A	12.12 c A	31,579 c A	27,857 c A
Sol da Manhã	16.27 a A	13.80 b A	24,798 d A	26,350 c A
Saracura	14.97 a A	16.46 b A	34,782 c A	31,724 b A
Cateto Sete Lagoas	7.83 c A	7.24 c A	28,935 d A	23,980 c A
Cimmyt 12	18.36 a A	17.92 b A	32,249 c A	27,452 c A
Cateto Sete Lagoas	7.83 c A	7.24 c A	28,935 d A	23,980 c A
Cimmyt 12	18.36 a A	17.92 b A	32,249 c A	27,452 c A

PH: plant height (m); TH: ear height (m); CD: stem diameter (mm); NT: total number of harvested ears; TPS: yield of ear with straw ready for silage (kg ha^{-1}); TPWS: yield of ear without straw ready for silage (kg ha^{-1}); GY: yield of grains ready for silage (kg ha^{-1}); GFM: proportion of grains in fresh weight (%) and FMY: fresh weight yield (kg ha^{-1}). Averages followed by the same letter do not differ statistically from one another, upper and lower case by the Scott-Knott clustering test P≤0.05.

This gain is fundamental, since the present study sought the simultaneous breeding of all the investigated traits. Therefore, it was the most suitable index for the selection of hybrids in the present work. The most significant predicted gains for yield of grains ready for silage (24.09%), yield of ear without straw ready for silage (17.55%) and ratio of grains in fresh weight (13.12%) were obtained with the application of Mulamba & Mock index. This index also allowed for satisfactory gains for the other evaluated traits, namely: plant height (with magnitude of 5.99%); ear height (6.69%); Stem diameter (2.32%); Number of ears (6.79%); Yield of ear with straw ready for silage (13.03%); and fresh weight production (12.58%) (Table 3). Berilli et al. (2013) used different selection indices for the selection of superior families in the eleventh cycle of reciprocal recurrent selection in corn and verified that the Mulamba & Mock index provided the best estimates of production gain (12.90%) when using weights attributed per trial. Cunha et al. (2012) also found that the Mulamba & Mock index presented the highest estimates of production gains (9.58%) when using weights attributed per trial in the selection of the superior families of the 12th cycle of reciprocal recurrent selection in corn. Freitas Júnior et al. (2009); Rangel et al. (2011); Freitas Júnior et al. (2013) also verified that the Mulamba & Mock index provided higher magnitudes of predicted gains for most traits evaluated when using arbitrary weights attributed per trial at different cycles of recurrent selection of popcorn in experiments conducted at the UENF. Regarding the Smith & Hazel and Willians selection index, the predicted gains were identical for all assessed traits, which demonstrate that the attributed values were not discrepant enough to change the predicted genetic gains (Table 3). The use of the Smith & Hazel and Willians indices provided lower percentage gain estimates for the yield of ear without straw ready for silage and yield of grains ready for silage compared to the Mulamba & Mock index, with estimates of 14, 34 and 11.22%, respectively (Table 3). In addition, the gain estimate for the trait GFM was negative when these indices were used, which does not favor the achievement of corn hybrids for silage. Thus, the use of both indices was not a good alternative for the selection of superior hybrids. Berilli et al. (2011) also used the Smith & Hazel index and obtained a gain of 14.26% for grain yield in a recurrent selection program in common corn. Differences between genetic gains predicted for grain yield were also verified by Tardin et al. (2007) when using this index in the 8th and 9th cycles of reciprocal recurrent selection in a corn population.

However, the use of the Pesek & Baker index resulted in undesirable gains for PH, TH, CD, NT and GFM, with estimates of -1,01; -1,67; -1,02; -1,74 and -2,75%, respectively. Therefore, it is not of interest for simultaneous breeding, since it leads to decreased plant height, lower ear height and smaller stem diameter, besides a reduced number of ears per plot and lower percentage of grains in the fresh weight (Table 3). The present study aimed at the simultaneous breeding of all variables assessed. Negative gains are undesirable in silage production. Thus, this index is not recommended for selection under the conditions of this work. Santos et al. (2007) predicted the genetic gains through the Pesek & Baker index in a popcorn population and observed unfavorable results of gains for some traits assessed. According to Deminicis et al. (2009), the ratio between biomass and grains is fundamental for silage quality. This proportion, in turn, directly affects animal nutrition efficiency. According to Demarquilly (1994) and Nussio (1991), the nutrition value of ensiled material is determined by the quality of the grain and fibrous fraction (stem, leaves, cob and straws). Table 4 shows the ranking and the averages of the 5 superior topcross hybrids selected by the Mulamba & Mock index.

The topcross hybrids presented high average for the yield of grains ready for silage and fresh weight yield, besides providing high average for the other traits analyzed.

Therefore, it is possible to verify that the Mulamba & Mock index showed the best results for the selection of corn hybrids for silage, providing not only satisfactory gains for GY and FMY, but also positive gains for the other traits desirable for the breeding of corn for silage in the Northern and Northwestern Rio de Janeiro.

Scott-Knott's clustering test

Table 5 shows the clustering test for the Scott-Knott averages for the seven traits evaluated in eight topcross hybrids and seven controls of corn for silage. Among the evaluated treatments, the superiority of the topcross hybrids for most traits assessed, mainly GY and FMY was observed compared to the controls belonging to the Flint heterotic group, whose hybrids were included in the most productive groups in relation to these controls.

This was already expected, since the controls of the "Flint" heterotic group are varieties and populations known for their inferior performance compared to the hybrids. However, this fact can be explained by the fact that the heterosis explored in the hybrids is certainly responsible for superiority compared to the varieties and populations.

The average clustering test revealed that for GY, the topcross hybrids presented averages close to those of the commercial control AG 1051 (8,988 kg ha^{-1}) and higher than that of the control UENF 506-11 (7,007 kg ha^{-1}), mainly the topcross hybrids UENF-2202, UENF-2210 and UENF-2209, in which they presented average of 8,417; 8,283 and 8,135 kg ha^{-1}, respectively (Table 5). It is also worth mentioning that the topcross hybrids UENF-2202, UENF-2210, and UENF-2209 belonged to the same clustering class as the control AG 1051. Paziani et al. (2009) evaluated agronomic traits in corn hybrids for silage production and obtained, on average, 6,916 kg ha^{-1} of production of corn ready for silage. It must be pointed out that the present study obtained superior results.

It is possible to observe that the heterotic intragroup hybrid combinations of the dent type were efficient and allowed the identification of topcross hybrids with agronomic performance superior or equivalent to that of the controls used. Table 6 presents the average values and respective clusterings based on the Scott-Knott test and the split of the genotype x location interaction for FMY. Four and three groups of genotypes were formed by the Scott- Knott clustering test for environment 1 and 2, respectively (Table 6).

It must be highlighted that, for site 2, the topcross hybrids UENF-2205, UENF-2208, UENF-2209, UENF-2210 and UENF 506-11 did not differ by the mean test and showed the highest indexes for fresh weight yield among the 15 genotypes assessed (Table 6).

The most productive genotypes showed fresh weight yield ranging from 39,932 to 46,416 kg ha^{-1}. They are promising, since the average FMY yield mentioned by Mendes (2012) was 41,960 kg ha^{-1} in the 2010/2011 agricultural year, in Lavras - MG. In contrast, Santos et al. (2010) obtained, on average, 33,800 kg ha^{-1} of FMY, while assessing corn varieties for silage production.

Regarding site 1, it was verified that the topcross hybrids UENF 2208 and UENF 2209 also presented the best performances, with FMY of 54,580 and 53,751 kg ha^{-1}, respectively.

The controls belonging to the Flint heterotic group (Composto Flint Normal, Sol da manhã, Saracura, Cateto Sete Lagoas and Cimmyt 12) were statistically different by the Scott-Knott test, and formed the genotype group with the lowest rates of fresh weight yield (Table 6). The results allowed identifying topcross hybrids with performance equal to or higher than that of the controls tested for the yield of grains ready for silage and fresh weight yield.

Materials and Methods

Plant materials and experimental design

The genotypes were obtained from the corn collection of the Universidade Estadual do Norte Fluminense Darcy Ribeiro. Eight genotypes were selected from the “Dent” heterotic groups for achieving topcross hybrids. Each genotype was crossed with tester, Piranão 12. It has a broad genetic base and also belongs to the "Dent" heterotic group. Thus, it could generate dent topcross hybrids (Table 1).

The topcross hybrids were obtained in an isolated field at the Estação Experimental da Ilha Barra do Pomba (Experimental Station of Ilha Barra do Pomba) in Itaocara, Northwestern Rio de Janeiro.

Each genotype was grown in lines of 10.0 m in length, with spacing of 1.0 m between rows and five seeds per linear meter, totally 50 plants per line spaced 0.20 m from each other.

During the flowering season, the detasseling of the females was conducted before the ears released the style-stigmas to avoid undesirable crosses. Thus, the style-stigmas received pollen only from the tester. The harvest was performed 120 days after sowing.

The trials for the evaluation of the topcross hybrids were implemented simultaneously at the Escola Técnica Estadual Agrícola Antônio Sarlo (Antônio Sarlo State Technical School), in Campos dos Goytacazes - RJ, and at the Estação Experimental da Ilha Barra do Pomba (Experimental Station at Ilha Barra do Pomba), in Itaocara - RJ, in the agricultural year of 2015/2016. These counties are located at 21° 24' 48" South, 41° 44' 48" West, 14m altitude. The mean rainfall is 108.6 mm, whereas the mean temperature is 27.27°C; and at 21° 40' 09" South and 42° 04' 34" West, 60m altitude, the mean rainfall is 183.25 mm, whereas the mean temperature is 25.32°C, respectively (INMET, 2017).

The experiment was arranged in a randomized block design with six replicates, each with 15 treatments; eight topcrosses and seven controls (Table 1). The experimental unit consisted of a line of 8.0 m with spacing of 1.0 between lines and 0.2 m between plants, totaling 40 plants per plot.
Three seeds were sown in each pit. Thinning was performed 21 days after emergence, and one plant was left in each pit.
According to the soil analysis, the sowing fertilization consisted of the application of 800 kg ha^{-1} of the formulate N P K 4-14-8. Then, two topdressing fertilizations were applied: 300 kg ha^{-1} of the formulate NPK 20-00-20, 30 days after planting; and 200 kg ha^{-1} of urea, 45 days after planting. The treatments recommended for the crop were carried out (Fancelli and Dourado Neto, 2000).

Agronomic traits evaluated in the experiment

The following agronomic traits were evaluated: mean plant height (PH), soil level measurements up to the tassel insertion node (m); Average height of insertion of the first ear (TH), measured from the ground to the base of the upper ear on the stem (in m); Stem mean diameter (CD), measured at the first internode above the plant collar (in mm); Total number of harvested ears (NT), yield of ear with

straw ready for silage (TPS) (in kg ha^{-1}); Yield of ear without straw ready for silage (TPWS) (in kg ha^{-1}); Yield of grains ready for silage (GY), (in kg ha^{-1}); Ratio of grains in the fresh weight (GFM) (in%) and fresh weight yield (FMY) (in kg ha^{-1}).
PH, TH and CD were randomly collected from six plants in the plot 80 days after planting. NT was obtained by counting the total number of ears harvested from the plot; TPS and TPWS were obtained from the weights of the ears with and without straw, when they were ready for silage; GY was obtained from the weighing of the threshed ears ready for silage; GFM was obtained by the ratio between GY and FMY; and FMY was obtained from the weighing of the plants (leaf + stem + ear) of each plot at the time of harvest.

The traits NT, TPWS, TPS, GY, GFM and FMY were measured 90 days after planting, in 20 plants per plot (totally 4.0 m of each line in the plot). Harvesting was performed by cutting the plants at the height of 20 cm from the soil, when the grains were at a farinaceous stage.

Statistical analysis

Initially, an analysis of variance was performed for each of the environments separately, in order to test the homogeneity of the mean squared error, by applying the Hartley test. The Shapiro-Wilk test was used to test data normality. After verifying the homogeneity and normality of the data, the joint analysis of variance was performed.
The joint analysis of variance was carried gusing the following statistical model:

$$Y_{ijk} = \mu + G_i + B/A_{jk} + A_j + GA_{ij} + e_{ijk}$$

Where: Y_{ijk} is the observation in the k-th block, evaluated in the i-th genotype and j-th environment; μ is the general constant of the trial; G_i is the fixed effect of genotype i, B/A_{jk} is the effect of block k in the environment j; A_j is the fixed effect of environment j; GA_{ij} is the effect of the interaction between genotype i and environment j; and e_{ijk} is the random error associated with the observation $Y_{ijk,}\, e_{ijk} \sim NID(0, \sigma^2)$.

The gains obtained by the selection indices were estimated based on the average of the joint analysis of two studied environments. The following selection indices were used for gain prediction: Smith (1936) & Hazel (1943), Willians (1962), Pesek & Baker (1969) and Mulamba & Mock (1978). Selection intensity was defined as 33.33%. The economic weights attributed per trial were (1; 1; 1; 300; 50; 50; 300; 300 and 300), respectively, for each trait analyzed (PH, TH, CD, NT, TPS, TPWS, GY, GFM and FMY). The statistical analyses were performed using the Genes software system (Cruz, 2013). The average clustering criterion was applied according to the Scott and Knott method (1974) for the traits evaluated. The analyses were performed using the resources of the R software system (Lopez et al., 2015).

Conclusion

The results indicate that the topcross hybrids under study presented wide genetic variability. Among the four tested selection indexes, the Mulamba & Mock was the most suitable for the selection of corn hybrids for silage production. Among the genotypes evaluated, some topcross hybrids present good agronomic performance. The top-cross hybrids UENF-2202, UENF-2209, UENF-2210, UENF-2191 and UENF 506-11 presented high potential for silage production in the Northern and Northwestern Rio de Janeiro.

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