PAB
Pesquisa Agropecuária Brasileira

ISSN 1678-3921

Journal homepage: www.embrapa.br/pab

For manuscript submission and journal contents, access: www.scielo.br/pab

Genetics/ Original Article

Selection indexes in the simultaneous increment of yield components in topcross hybrids of green maize

Willame dos Santos Candido[(1 ✉)], Caique Machado e Silva[(1)], Maraiza Lima Costa[(1)], Bruna Elaine de Almeida Silva[(1)], Beatriz Lima de Miranda[(1)], Jefferson Fernando Naves Pinto[(1)] and Edésio Fialho dos Reis[(1)]

[(1)] Universidade Federal de Jataí, Campus Riachuelo, Rua Riachuelo, nº 1.530, Setor Samuel Grahan, CEP 75804-020 Jataí, GO, Brazil.
E-mail: candidows.melhorista@gmail.com, caiquems08@gmail.com, maraiza-15@hotmail.com, brunaelainea@gmail.com, beatrizlimaa977@gmail.com, jeffnaves@gmail.com, edesiofr7@gmail.com

✉ Corresponding author

Received
December 23, 2018

Accepted
November 7, 2019

How to cite
CANDIDO, W. dos S.; SILVA, C.M. e; COSTA, M.L.; SILVA, B.E. de A.; MIRANDA, B.L. de; PINTO, J.F.N.; REIS, E.F. dos. Selection indexes in simultaneous increment of yield components in topcross hybrids of green maize. **Pesquisa Agropecuária Brasileira**, v.55, e01206, 2020. DOI: https://doi.org/10.1590/S1678-3921.pab2020.v55.01206.

Abstract – The objective of this work was to define the most suitable selective strategy for the simultaneous increment of yield components of green maize, by comparing three selection indexes weighted by economic weights and by the REML/BLUP method, in the assessment of predicted genetic gains for traits of interest. An experiment with 75 topcross hybrids from partially inbred S_1 lines of green maize was carried out in Jataí, in the state of Goiás, Brazil, using a randomized complete block design, with four replicates. The following yield traits were evaluated: straw ears and commercial ears, grain mass, ear length, ear diameter, and number of ear rows. The selection indexes of Smith and Hazel, Williams, and Mulamba & Mock were applied and weighted for four economic weights (1, CV_g, CV_g/CV_e, and h^2). Among the tested selection indexes, those of Williams and Mulamba & Mock are the best-fit ones for the selection of topcross hybrids of green maize, as they provide positive and more balanced selection gains for all evaluated traits. The REML/BLUP method shows better predicted genetic gains than those achieved by the three selection indexes, besides being efficient for the selection of topcross hybrids of green maize.

Index terms: *Zea mays*, economic weights, mixed models, REML/BLUP.

Índices de seleção no incremento simultâneo de componentes de produção dos híbridos topcross de milho verde

Resumo – O objetivo deste trabalho foi determinar a estratégia seletiva mais adequada para o incremento simultâneo de componentes da produção de milho verde, pela comparação de três índices de seleção, ponderados por pesos econômicos, e pelo método REML/BLUP, na avaliação de ganhos genéticos previstos para os caracteres de interesse. Um ensaio com 75 híbridos topcross, de linhagens S_1 parcialmente endogâmicas de milho-verde foi implementado em Jataí, GO, Brasil, tendo-se utilizado um delineamento de blocos ao acaso, com quatro repetições. As seguintes características de produtividade foram avaliadas: espigas empalhadas e espigas comerciais, massa de grãos, comprimento de espiga, diâmetro de espiga e número de fileiras da espiga. Os índices de seleção de Smith e Hazel, Williams e de Mulamba & Mock foram aplicados e ponderados por quatro pesos econômicos (1, CV_g, CV_g/CV_e e h^2). Entre os índices de seleção testados, o de Williams e os de Mulamba & Mock são os melhores para a seleção de híbridos de milho verde, pois proporcionam ganhos de seleção positivos e mais equilibrados em todos os caracteres avaliados. O método REML/BLUP apresenta melhores ganhos genéticos preditos do que os obtidos pelos três índices de seleção estudados, além de ser eficiente para a seleção de híbridos topcross de milho verde.

Termos para indexação: *Zea mays*, pesos econômicos, modelos mistos, REML/BLUP.

Introduction

The cultivation of maize (*Zea mays* L.) for green-maize production is one of the most significant agricultural activities in Brazil. The ears are harvested with immature grains with a moisture content between 70 and 80%. This product is appreciated throughout the country, and is consumed fresh or cooked for various dishes, or even industrialized and sold as canned green corn (DoVale et al., 2011; Favarato et al., 2016), which increases the economic value of the final product, encouraging farmers to increase their incomes.

According to Ferreira et al. (2009), a green-maize cultivar should attend consumer's requirements by exhibiting superior agronomic traits. In this regard, plant breeders are challenged to evaluate an elevated progeny number and select the most promising ones to form the recombination fields, and then compose the new populations to proceed with the crop breeding program. Thus, in the selection stage, the indexes can become a useful strategy to assist breeders in the simultaneous selection of traits related to yield components, aiming to obtain high-genetic gains with each recurrent selection cycle.

A simultaneous selection of multiple traits can be performed by different methods. Among the available methodologies, the classical index proposed by Smith (1936) and Hazel (1943), the selection base index proposed by Williams (1962), and the index of sum of ranks proposed by Mulamba & Mock (1978) are highlighted. Therefore, a simultaneous selection of several traits offers a greater chance of success with the selection of promising genotypes for the market (Rodrigues et al., 2011).

Besides the use of selection indexes, a widely used alternative with great accuracy in the selection process is the use of variance components estimated by the restricted maximum likelihood (REML) and the genetic or genotypic values predicted by the best linear unbiased predictor (BLUP) (Rodrigues et al., 2013). These procedures provide additional relevant parameters for the identification of superior genotypes (Maia et al., 2011; Ramalho & Araújo, 2011; Freitas et al., 2013; Gomes et al., 2018).

There are several studies that use the index methodology to predict genetic gains for maize selection (Amaral Júnior et al., 2010; Freitas et al., 2013; Vieira et al., 2017; Lima et al., 2018). However, studies on green-maize topcross hybrids – in which one of the parents is an open-pollinated variety, and the other is a single-cross hybrid, or an inbred line – using index-based selection and REML/BLUP strategies are still scarce.

The objective of this work was to define the most suitable selective strategy for the simultaneous increment of yield components of green maize, by comparing three selection indexes weighted by economic weights and by the REML/BLUP method, in the assessment of predicted genetic gains for traits of interest.

Materials and Methods

Topcross hybrids used in the experiment came from partially inbred S_1 lines, originated from the population TG02R2, that show potential for green maize production. The lines were crossed with a broad genetic base tester (F_2 of hybrid AG 1051) according to the Irish method (Paterniani, 1993). To carry out the crosses, seed from the selected S_1 families were sown in a 5 m line and, at every three line, a tester line was sown. In July 2017, the planting was performed in an isolated area with drip irrigation. The experimental field was located at 17º53'S and 52º43'W, at 680 m altitude, in the municipality of Jataí, in the state of Goiás, Brazil, whose climate is Aw type, according to the Köppen-Geiger's classification, that is, a tropical savannah with raining summer and dry winter, and the soil is characterized as a Latossolo Vermelho distroférrico (Santos et al., 2013), which is equivalent to an Oxisol witch clayey texture.

When male flowering took place, the emasculation of the S_1 lines was performed to allow of only the tester to supply pollen; then, 75 topcross hybrids (TG02R2 x AG 1051) were generated. At harvest, a visual assessment of the ears was made, and those with undesirable agronomic performance were discarded. Best quality ears of were used to compose the material for the experimental evaluation.

The evaluation of the 75 topcross hybrids was carried out between February and May of 2018, in the second harvest (little crop), in the field. The experiment was set up in a randomized complete block design with four replicates, and each replicate consisted of four lines of 4 m, containing a total of 20 plants per line. The plots were made up of 4 m rows spaced at 0.90 m between rows and 0.20 m between plants.

On the installation of the field experiment, the pre-planting fertilization was performed at 400 kg ha^{-1} in the ratio 04-20-18 of N-P_2O_5-K_2O, and then two cover fertilizations of 200 kg ha^{-1} ammonium sulfate took place.

Eighty-two days after sowing, a sample of five plants, with five ears in total, were used in each plot for the evaluation of grain mass, ear length, ear diameter, and number of ear rows. Evaluations for the traits straw ear yield and commercial ear yield were performed for the total of plants per plot. The stand was corrected for 20 plants per plot. The measurements were made as follows: straw ear yield (SEYIELD) was achieved by adding the total weight of the straw ears of each replicate, and the data were transformed (kg ha^{-1}); commercial ear yield (CEYIELD) was derived from the sum of the weighing of hulled ears larger than 15 cm, with a diameter greater than 3 cm, and free of pests and diseases, and data collected were transformed (kg ha^{-1}); grain mass (MASS, g) was obtained after the removal of the grain mass of five ears representative of the plot, by cutting of the grains at the base of the cob and subsequent weighing; ear length (EL, cm) was reached by measuring the length of five representative ears of the replicate; ear diameter (ED, cm) was determined by measuring the diameter of five ears representative of the replicate; number of ear rows (NER) was calculated by counting the grain rows in five ears representative of the replicate.

The selection indexes applied for the selection of 75 topcross hybrids from partially inbred S_1 lines were those of Smith (1936) and Hazel (1943), Williams (1962), and Mulamba & Mock (1978). The selection of superior hybrids, based on selection indexes, was conducted using the statistical software Genes (Cruz, 2013).

The classical index (Smith, 1936; and Hazel, 1943) was determined by the following estimator:

$$I_i = \sum_k b_k \bar{y}_{ik},$$

in which: I_i is the value of the index calculated for the progeny i; b_k is the weighting coefficient of the index associated with the trait k; and $\bar{y}_{ik}$ is the phenotypic mean of the progeny i relatively to the trait k. The b_k values were estimated by $b = P^{-1}G \times a$, in which: P^{-1} is the inverse of the mean phenotypic covariance matrix between traits; G values represent the genotypic variance and covariance matrices in progeny mean between traits; and a represent the economic weights of trait vectors.

The base index (Williams, 1962) was obtained by the estimator:

$$I_i = \sum_k b_k a \bar{y}_{ik},$$

The sum of ranks of Mulamba & Mock (1978) index was calculated by the expression:

$$I_i = \sum_k a r_{ik},$$

in which: r_{ik} is the rank of the progeny i for the trait k.

The economic weights for all traits to the three indexes were applied according to the following strategies: weight 1; coefficient of genetic variation (CV_g); CV_g/CV_e ratio between the genetic variation coefficient (CV_g) and the environmental variation coefficient (CV_e); and broad heritability of the trait.

For each trait, the selection gains were estimated by indexes according to Cruz & Carneiro (2006). The indexes analysis was executed with the software Genes (Cruz, 2013).

The Selegen-REML/BLUP software was adopted for the statistical analysis of mixed models (Resende, 2016). Statistical model 21 (complete blocks) was used as $y = Xr + Zg + e$, in which: y is the data vector; r is the replicate vector of effects (assumed as fixed) plus the overall mean; g is the genotypic effect vector (assumed as random); and e is the error, or residual vector (random). Capital letters represent the incidence matrices for these effects.

The genetic values of each topcross hybrid were calculated by summing each genotypic effect (g) to the overall mean of the trial (u). The genetic gain equals the mean of the predicted genetic effect vectors for the selected hybrids (Freitas et al., 2013), for which 10.67% selection intensity was adopted, and from which eight topcross hybrids were selected. The overall mean added to the genetic gain resulted in the mean of the improved population.

DOI: 10.1590/S1678-3921.pab2020.v55.01206

Results and Discussion

The genetic variability among the evaluated hybrids is included, proving to be promising to obtain genetic gains, by selection, for the majority of the traits (Table 1).

The classical index of Smith (1936) and Hazel (1943) showed a high-predicted genetic gain for CEYIELD, when weighted by weights 1, CVg, CVg/CVe, and h², with mean values of 19.20, 22.24, 21.22, and 21.28% respectively, which stood out as the greater predicted gains than the those of other indexes (Table 2). Results of the present study corroborate those by Rangel et al. (2011), Freitas et al. (2013), Entringer et al. (2016), and Crevelari et al. (2018), who indicated positive genetic gains for traits of maize crop yield when using the index of Smith (1936) and Hazel (1943).

Despite the positive gains from commercial ear yields, they were low when compared to gains for the same trait obtained by the REML/BLUP methodology (27.32%) (Table 2). Vittorazzi et al. (2017) achieved similar results in genetic gains when applying the REML/BLUP methodology for the analysis of popcorn yield. Furthermore, it can be observed that, for the same index, negative gains resulted for the NER trait when the economic weights used were 1, CV_g, CV_g/CV_e, and h², pointing out to a reduction of the trait, which may be an undesirable factor in advancing the maize breeding program. In the present study, gains for the NER trait were 6.12%, according to the REML/BLUP methodology. The number of rows is known to be an important trait, as the ears with a greater number of rows provide ears that are better shaped and, consequently, better appreciated by consumers. Thus, these results do not enable us to state that the index of Smith (1936) and Hazel (1943) is the most appropriate for the selection of topcross hybrids of green maize.

The use of the Mulamba & Mock (1978) index evidenced gains in the ED and NER traits weighted by all weights (1, CV_g, CV_g/CV_e, and h²), in comparison with all the other indexes under study (Table 2). Our findings for the estimates of positive genetic gains based on the Mulamba & Mock (1978) index corroborate those achieved by Crevelari et al. (2017) for hybrid maize traits – for silage –, and by Amaral Júnior et al. (2010), Freitas et al. (2014), and Guimarães et al. (2018) – for popcorn. However, when comparing the estimated gains via REML/BLUP, higher-predicted gains were again evidenced, suggesting that the REML/BLUP methodology shows a higher accuracy for genotype selection.

Using the index of Williams (1962), or base index, in general, resulted in higher gains than that of the classical index of Smith (1936) and Hazel (1943), when employed as an economic weight for the traits equal to 1.

The Mulamba & Mock (1978) and Williams (1962) indexes allowed of the prediction of positive gains for all studied traits. The highest-predicted gain values for the SEYIELD trait were determined using the Williams (1962) index weighted by weights 1, CV_g/CV_e, and h², which was 11.93% (Table 2). For the characters CEYIELD, MASS, and EL, the greatest gains – 22.24, 6.56 and 3.54%, respectively – were found when the Smith (1936) and Hazel (1943) index was applied, and when they were weighted by CV_g. For the ED and NER traits, the greatest gains – 2.54

Table 1. Genetic and phenotypic parameters for yield traits of 75 topcross hybrids (TG02R2 x AG 1051) from partially inbred S_1 lines of green maize (*Zea mays*), in the municipality of Jataí, in the state of Goiás, Brazil(1).

Parameter	SEYIELD (kg ha^{-1})	CEYIELD (kg ha^{-1})	MASS (g)	EL (cm)	ED (cm)	NER
σ^2_g	1,479,613.74	762,116.42	73.34	0.33	0.01	0.27
σ^2_e	2,599,657.91	2,064,040.56	442.15	1.02	0.06	1.91
CV_g (%)	8.29	16.43	6.55	3.18	2.47	3.48
CV_e (%)	10.99	27.03	16.08	5.61	5.15	9.2
CV_g / CV_e	0.75	0.61	0.41	0.57	0.48	0.38
Heritability (%)	69.48	59.63	39.88	56.26	47.94	36.42

(1)SEYIELD, straw ear yield; CEYIELD, commercial ear yield; MASS, mean weight of grain mass; EL, ear length; ED, ear diameter; and NER, number of ear rows. Parameter: σ^2_g, genotypic variance; σ^2_e, environmental variance; CV_g (%), genetic variation coefficient; CV_e (%), environmental variation coefficient.

DOI: 10.1590/S1678-3921.pab2020.v55.01206

and 1.20%, respectively – were noted when the Mulamba & Mock (1978) index was used, weighted by weight 1. From these results, it can be observed that the application of Smith (1936) and Hazel (1943) and Mulamba & Mock (1978) indexes, weighted by CV_g and 1, respectively, may signal gains for important yield component traits of green maize.

The REML/BLUP stood out as the most efficient methodology in comparison to the other tested indexes for all weights considered, as simultaneous enhancements were seen for genetic gains of the following traits: SEYIELD, CEYIELD, MASS, EL, ED, and NER, with percentage gains of about 13.43, 27.32, 8.40, 4.28, 3.37, and 6.12, respectively.

This difference for genetic gains (which resulted from the applied methodology and selection indexes) can be attributed to the use of the predicted genotypic effects and the selection gains for each hybrid, as a

Table 2. Estimates for selection gains of yield traits in 75 topcross hybrids (TG02R2 x AG 1051) of green maize (*Zea mays*) from partially inbred S_1 lines, by the indexes proposed by Smith (1936) and Hazel (1943), Mulamba & Mock (1978), and Williams (1962), with economic weights (1, coefficient of genetic variation - CV_g, CV_g/CV_e ratio, and broad trait heritability) and the REML/BLUP methodology, in the municipality of Jataí, in the state of Goiás, Brazil.

Weight	Smith and Hazel	Mulamba & Mock	Williams	REML/BLUP
		Straw ear yield (SEYIELD, kg ha^{-1})		
1	11.91	10.86	11.93	13.43
CV_g	11.21	11.67	10.9	
CV_g/CV_e	11.68	11.5	11.93	
h^2	11.66	11.5	11.93	
		Commercial ear yield (CEYIELD, kg ha^{-1})		
1	19.20	15.18	19.60	27.32
CV_g	22.24	19.79	21.14	
CV_g/CV_e	21.22	18.4	19.6	
h^2	21.28	18.4	19.6	
		Mean weight of grain mass (MASS, g)		
1	3.88	5.47	4.58	8.40
CV_g	6.56	4.84	3.59	
CV_g/CV_e	6.39	5.05	4.58	
h^2	6.4	5.05	4.58	
		Ear length (EL, cm)		
1	2.72	1.98	2.51	4.28
CV_g	3.54	2.43	2.16	
CV_g/CV_e	3.34	2.35	2.51	
h^2	3.36	2.35	2.51	
		Ear diameter (ED, cm)		
1	1.50	2.54	1.70	3.37
CV_g	1.37	1.76	1.37	
CV_g/CV_e	1.44	2.09	1.7	
h^2	1.44	2.09	1.7	
		Number of ear rows (NER)		
1	-0.47	1.20	0.08	6.12
CV_g	-1.72	0.05	0.14	
CV_g/CV_e	-1.38	0.41	0.08	
h^2	-1.4	0.41	0.08	

solution vector, by the REML/BLUP. This corrects the values of environmental effects, predicting the genotypic values in a precise and nonbiased manner, which leads to a maximizing of the genetic gains with the selection (Freitas et al., 2013; Rodrigues et al., 2013; Silva et al., 2017; Gomes et al., 2018).

By the REML/BLUP method, the estimates of the overall mean (u) of the experiment were: SEYIELD (14,670.92 kg ha^{-1}); CEYIELD (5,314.96 kg ha^{-1}); MASS (130.77 g); EL (18.05 cm;ED (4.61 cm); and NER (15.04 rows). Taking into account the achieved gains and the new mean, the performance of the eight selected hybrids showed higher estimates than the overall mean of the experiment for all traits, proving the selective accuracy of the REML/BLUP methodology (Table 3). For the straw ear yield and the commercial ear yield, 75% of the selected hybrids coincided using REML/BLUP. Therefore, the method proved to be much more efficient than the selection indexes, as it selected hybrids with high performance and promising predicted genetic gains for green maize, as it was also observed in the results of Freitas et al. (2013) for popcorn crop.

Table 3. Rank and estimates for yield traits of eight superior topcross hybrids for selection of 75 topcross hybrids (TG02R2 x AG 1051) of green maize *(Zea mays)* from partially inbred S_1 lines, in the municipality of Jataí, in the state of Goiás, Brazil(1).

Rank	Hybrid	g	u + g	Gain	New mean	Hybrid	g	u + g	Gain	New mean
	SEYIELD (kg ha^{-1})					CEYIELD (kg ha^{-1})				
1	10	2,122.97	16,793.89	2,122.97	16,793.89	19	1,977.09	7,292.05	1,977.09	7,292.05
2	19	2,071.07	16,741.99	2,097.02	16,767.94	48	1,515.69	6,830.64	1,746.39	7,061.35
3	5	1,995.72	16,666.64	2,063.25	16,734.18	6	1,160.87	6,475.82	1,551.22	6,866.17
4	6	1,873.92	16,544.84	2,015.92	16,686.84	28	1,085.49	6,400.45	1,434.79	6,749.74
5	25	1,843.06	16,513.98	1,981.35	16,652.27	42	954.84	6,269.79	1,338.80	6,653.75
6	2	1,557.41	16,228.33	1,910.69	16,581.61	25	806.70	6,121.66	1,250.11	6,565.07
7	42	1,282.94	15,953.86	1,821.01	16,491.94	5	786.69	6,101.65	1,183.91	6,498.87
8	48	1,255.68	15,926.60	1,750.35	16,421.27	40	784.21	6,099.16	1,133.95	6,448.90
	MASS (g)					EL (cm)				
1	8	13.53	144.30	13.53	144.30	5	0.96	19.00	0.96	19.00
2	42	10.34	141.11	11.93	142.70	21	0.73	18.78	0.85	18.89
3	61	10.28	141.05	11.38	142.15	69	0.71	18.75	0.80	18.84
4	25	9.14	139.91	10.82	141.59	2	0.65	18.69	0.76	18.81
5	48	9.14	139.91	10.49	141.25	10	0.62	18.67	0.73	18.78
6	10	8.45	139.21	10.15	140.91	59	0.59	18.64	0.71	18.76
7	5	8.25	139.01	9.87	140.64	24	0.57	18.61	0.69	18.74
8	27	8.15	138.91	9.66	140.43	11	0.55	18.59	0.67	18.72
	ED (cm)					NER				
1	8	0.19	4.80	0.19	4.80	45	1.66	16.70	1.66	16.70
2	6	0.16	4.77	0.17	4.79	8	0.60	15.65	1.13	16.17
3	18	0.14	4.75	0.16	4.77	57	0.60	15.65	0.95	16.00
4	57	0.14	4.75	0.16	4.77	64	0.53	15.57	0.85	15.89
5	5	0.11	4.73	0.15	4.76	16	0.46	15.50	0.77	15.81
6	25	0.11	4.73	0.14	4.75	42	0.42	15.46	0.71	15.76
7	60	0.11	4.73	0.14	4.75	32	0.38	15.43	0.67	15.71
8	61	0.11	4.73	0.14	4.75	44	0.31	15.36	0.62	15.66

(1)Estimates: g, effects; u+g, predicted genotypic values, and the new predicted mean (REML/BLUP). Traits: SEYIELD, straw ear yield; CEYIELD, commercial ear yield; MASS, mean weight of grain mass; EL, ear length; ED, ear diameter; and number of ear rows (NER).

Conclusion

The REML/BLUP is the most efficient methodology, in comparison to the selection indexes of Smith and Hazel, Williams, and Mulamba & Mock which were applied to all weights considered, with simultaneous enhancements observed in genetic gains for the following traits: straw ear yield, commercial ear yield, mean weight of grain mass, ear length, ear diameter, and number of ear rows in 75 topcross hybrids (TG02R2 x AG 1051) of green maize (*Zea mays*) from partially inbred S1 lines

Acknowledgments

To Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (Capes), for the postdoctoral fellowship granted to the first author (finance code 001); to Fundação de Amparo à Pesquisa do Estado de Goiás (Fapeg), and to Universidade Federal de Goiás, Campus Jataí, for the support to the research.

References

AMARAL JÚNIOR, A.T.; FREITAS JÚNIOR, S.P.; RANGEL, R.M.; PENA, G.F.; RIBEIRO, R.M.; MORAIS, R.C.; SCHUELTER, A.R. Improvement of a popcorn population using selection indexes from a fourth cycle of recurrent selection program carried out in two different environments. **Genetics and Molecular Research**, v.9, p.340-347, 2010. DOI: https://doi.org/10.4238/vol9-1gmr702.

CREVELARI, J.A.; DURÃES, N.N.L.; BENDIA, L.C.R.; SILVA, A.J. da; PEREIRA, M.G. Prediction of genetic gains and correlations in corn hybrids for silage. **Australian Journal of Crop Science**, v.11, p.1411-1417, 2017. DOI: https://doi.org/10.21475/ajcs.17.11.11.pne539.

CREVELARI, J.A.; DURÃES, N.N.L.; BENDIA, L.C.R.; SILVA, A.J. da; AZEVEDO, F.H.V.; AZEREDO, V.C.; PEREIRA, M.G. Assessment of agronomic performance and prediction of genetic gains through selection indices in silage corn. **Australian Journal of Crop Science**, v.12, p.800-807, 2018. DOI: https://doi.org/10.21475/ajcs.18.12.05.PNE1004.

CRUZ, C.D. GENES - a software package for analysis in experimental statistics and quantitative genetics. **Acta Scientiarum. Agronomy**, v.35, p.271-276, 2013. DOI: https://doi.org/10.4025/actasciagron.v35i3.21251.

CRUZ, C.D.; CARNEIRO, P.C.S. **Modelos biométricos aplicados ao melhoramento genético**. 2.ed. Viçosa: UFV, 2006. v.2, 585p.

DOVALE, J.C.; FRITSCHE-NETO, R.; SILVA, P.S.L. e. Índice de seleção para cultivares de milho com dupla aptidão: minimilho e milho verde. **Bragantia**, v.70, p.781-787, 2011. DOI: https://doi.org/10.1590/S0006-87052011000400008.

ENTRINGER, G.C.; VETTORAZZI, J.C.F.; SANTOS, E.A.; PEREIRA, M.G.; VIANA, A.P. Genetic gain estimates and selection of S_1 progenies based on selection indices and REML/BLUP in super sweet corn. **Australian Journal of Crop Science**, v.10, p.411-417, 2016. DOI: https://doi.org/10.21475/ajcs.2016.10.03.p7248.

FAVARATO, L.F.; SOUZA, J.L.; GALVÃO, J.C.C.; SOUZA, C.M. de; GUARCONI, R.C.; BALBINO, J.M. de S. Crescimento e produtividade do milho-verde sobre diferentes coberturas de solo no sistema plantio direto orgânico. **Bragantia**, v.75, p.497-506, 2016. DOI: https://doi.org/10.1590/1678-4499.549.

FERREIRA, R.; GARDINGO, J.R.; MATIELLO, R.R. Seleção de progênies de irmãos germanos destinadas à produção de milho-verde. **Scientia Agraria**, v.10, p.23-30, 2009. DOI: https://doi.org/10.5380/rsa.v10i1.12763.

FREITAS, I.L. de J.; AMARAL JUNIOR, A.T. do; VIANA, A.P.; PENA, G.F.; CABRAL, P. da S.; VITTORAZZI, C.; SILVA, T.R. da C. Ganho genético avaliado com índices de seleção e com REML/BLUP em milho-pipoca. **Pesquisa Agropecuária Brasileira**, v.48, p.1464-1471, 2013. DOI: https://doi.org/10.1590/S0100-204X2013001100007.

FREITAS, I.L.J.; AMARAL JÚNIOR, A.T. do; FREITAS JR., S.P.; CABRAL, P.D.S.; RIBEIRO, R.M.; GONÇALVES, L.S.A. Genetic gains in the UENF-14 popcorn population with recurrent selection. **Genetics and Molecular Research**, v.13, p.518-527, 2014. DOI: https://doi.org/10.4238/2014.January.21.21.

GOMES, A.B.S.; OLIVEIRA, T.R.A.; CRUZ, D.P.; GRAVINA, G.A.; DAHER, R.F.; ARAÚJO, L.C.; ARAÚJO, K.C. Genetic gain via REML/BLUP and selection indices in snap bean. **Horticultura Brasileira**, v.36, p.195-198, 2018. DOI: https://doi.org/10.1590/S0102-053620180208.

GUIMARÃES, A.G.; AMARAL JÚNIOR, A.T. do.; LIMA, V.J. de; LEITE, J.T.; SCAPIM, C.A.; VIVAS, M. Genetic gains and selection advances of the UENF-14 popcorn population. **Revista Caatinga**, v.31, p.271-278, 2018. DOI: https://doi.org/10.1590/1983-21252018v31n202rc.

HAZEL, L.N. The genetic basis for constructing selection indexes. **Genectics**, v.28, p.476-490, 1943.

LIMA, V.J. de; FREITAS JUNIOR, S. de P.; SOUZA, Y.P. de; SILVA, C.S. da; FARIAS, J.E.C.; SOUZA, R.F. de; CHAVES, M.M.; FEITOSA, J.V. Genetic gain capitalization in the first cycle of recurrent selection in popcorn at Ceará's Cariri. **Revista Brasileira de Ciências Agrárias**, v.13, e5556, 2018. DOI: https://doi.org/10.5039/agraria.v13i3a5556.

MAIA, M.C.C.; RESENE, M.D.V. de; OLIVEIRA, L.C. de; ÁLVARES, V. de S.; MACIEL, V.T.; LIMA, A.C. de. Seleção de clones experimentais de cupuaçu para características agroindustriais via modelos mistos. **Revista Agro@mbiente**, v.5, p.35-43, 2011.

MULAMBA, N.N.; MOCK, J.J. Improvement of yield potential of the Eto Blanco maize (*Zea mays* L.) population by breeding for plant traits. **Egyptian Journal of Genetics and Cytology**, v.7, p.40-51, 1978.

PATERNIANI, E. Métodos tradicionais de melhoramento de milho. In: BULL, L.T.; CANTARELLA, H. (Ed). **Cultura do milho**: fatores que afetam a produtividade. Piracicaba: Potafós, 1993. p. 23-44.

RAMALHO, M.A.P.; ARAÚJO, L.C.A. de. Breeding self-pollinated plants. **Crop Breeding and Applied Biotechnology**, v.11, p.1-7, 2011. Número especial. DOI: https://doi.org/10.1590/S1984-70332011000500002.

RANGEL, R.M.; AMARAL JÚNIOR, A.T. do; GONÇALVES, L.S.A.; FREITAS JÚNIOR, S. de P.; CANDIDO, L.S. Análise biométrica de ganhos por seleção em população de milho pipoca de quinto ciclo de seleção recorrente. **Revista Ciência Agronômica**, v.42, p.473-481, 2011. DOI: https://doi.org/10.1590/S1806-66902011000200029.

RESENDE, M.D.V. de. Software Selegen-REML/BLUP: a useful tool for plant breeding. Crop Breeding and Applied Biotechnology, v.16, p.330-339, 2016. DOI: https://doi.org/10.1590/1984-70332016v16n4a49.

RODRIGUES, F.; PINHO, R.G. von; ALBUQUERQUE, C.J.B.; PINHO, E.V.R. von. Índice de seleção e estimativa de parâmetros genéticos e fenotípicos para características relacionadas com a produção de milho-verde. **Ciência e Agrotecnologia**, v.35, p.278-286, 2011. DOI: https://doi.org/10.1590/S1413-70542011000200007.

RODRIGUES, W.P.; VIEIRA, H.D.; BARBOSA, D.H.S.G.; SOUZA FILHO, G.R.; CANDIDO, L.S. Adaptability and genotypic stability of *Coffea arabica* genotypes based on REML/BLUP analysis in Rio de Janeiro State, Brazil. **Genetics and Molecular Research**, v.12, p.2391-2399, 2013. DOI: https://doi.org/10.4238/2013.July.15.2.

SANTOS, H.G. dos; JACOMINE, P.K.T.; ANJOS, L.H.C. dos ; OLIVEIRA, V.A. de; LUMBRERAS, J.F.; COELHO, M.R.; ALMEIDA, J.A. de; CUNHA, T.J.F.; OLIVEIRA, J.B. de. **Sistema brasileiro de classificação de solos**. 3.ed. rev. e ampl. Brasília: Embrapa, 2013. 353p.

SILVA, F.H. de L. e; VIANA, A.P.; SANTOS, E.A.; FREITAS, J.C. de O.; RODRIGUES, D.L.; AMARAL JÚNIOR, A.T. do. Prediction of genetic gains by selection indexes and REML/BLUP methodology in a population of sour passion fruit under recurrent selection. **Acta Scientiarum. Agronomy**, v.39, p.183-190, 2017. DOI: https://doi.org/10.4025/actasciagron.v39i2.32554.

SMITH, H.F. A discriminant function for plant selection. **Annals of Eugenics**, v.7, p.240-250, 1936. DOI: https://doi.org/10.1111/j.1469-1809.1936.tb02143.x.

VIEIRA, R.A.; ROCHA, R. da; SCAPIM, C.A.; AMARAL JUNIOR, A.T. do. Recurrent selection of popcorn composites UEM-CO1 and UEM-CO2 based on selection indices. **Crop Breeding and Applied Biotechnology**, v.17, p.266-272, 2017. DOI: https://doi.org/10.1590/1984-70332017v17n3n40.

VITTORAZZI, C.; AMARAL JÚNIOR, A.T.; GUIMARÃES, A.G.; VIANA, A.P.; SILVA, F.H.L.; PENA, G.F.; DAHER, R.F.; GERHARDT, I.F.S.; OLIVEIRA, G.H.F.; PEREIRA, M.G. Indices estimated using REML/BLUP and introduction of a super-trait for the selection of progenies in popcorn. **Genetics and Molecular Research**, v.16, gmr16039769, 2017. DOI: https://doi.org/10.4238/gmr16039769.

WILLIAMS, J.S. The evaluation of a selection index. **Biometrics**, v.18, p.375-393, 1962. DOI: https://doi.org/10.2307/2527479.