

Genetic gain capitalization in the first cycle of recurrent selection in popcorn at Ceará's Cariri

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ABSTRACT: Popcorn lacks cultivars that are productive, stable and adapted to the cultivation regions. Therefore, the present work aimed to estimate the genetic gain in the first intrapopulation recurrent selection cycle between full-sibs, by means of selection index, at Ceará's Cariri. It was obtained 210 families from the "Dona Iva" population, belonging to the Federal University of Cariri - UFCA's germplasm bank. The progenies were evaluated in two environments: Granjeiro-CE and at the experimental field at UFCA, Crato-CE, using randomized block design with two repetitions inside "sets". For the assessment, it was evaluated plant height (AP), ear height (AE), plant final stand (NP), mass of ear with grains (PE), grain yield (RG) and expansion capacity (CE). Data were submitted to analysis of variance by the F test and estimated genetic and phenotypic parameters. The prediction of the selection gains were obtained by the indexes of Mulamba and Mock and of Smith and Hazel. When the Smith and Hazel selection index was evaluated, it was not possible to predict gains for CE. On the other hand, Mulamba and Mock selection index with the economic weight PA (arbitrage weight by attempt) provided the highest gain for expansion capacity (8.15%) and elevated gain for RG (24.29%). Therefore, based on this weight it was selected 38 superior genotypes for recombination and the aforementioned gains are expected in the first selection cycle of the "Iva" popcorn population.

Key words: expansion capacity; genetic parameters; selection index; *Zea mays* L. var. *everta*

Capitalização de ganhos genéticos no primeiro ciclo de seleção recorrente de milho-pipoca no Cariri Cearense

RESUMO: O milho-pipoca carece de cultivares produtivos, estáveis e adaptados as regiões de cultivo. Diante disso, o presente trabalho objetivou estimar o ganho genético no primeiro ciclo de seleção recorrente intrapopulacional no Cariri Cearense entre famílias de irmãos completos, por meio de índices de seleção. Foram obtidas 210 famílias da população "Dona Iva", pertencente ao banco de germoplasma da Universidade Federal do Cariri – UFCA. As progênes foram avaliadas em dois ambientes: Granjeiro-CE e no campo experimental da UFCA, Crato-CE, em delineamento blocos casualizados com duas repetições dentro de 'sets'. Para fins de avaliação, foi aferida a altura da planta (AP) e espiga (AE), estande final de plantas (NP), massa de espiga com grãos (PE), rendimento de grãos (RG) e capacidade de expansão (CE). Os dados foram submetidos à análise de variância pelo teste F e estimado os parâmetros genéticos e fenotípicos. As predições dos ganhos por seleção foram obtidas pelos índices de Mulamba e Mock e de Smith e Hazel. Avaliando o índice de seleção de Smith e Hazel, não foi possível prever ganhos simultâneos para CE. Por sua vez, no índice de seleção de Mulamba e Mock, com o peso econômico PA (peso arbitrário por tentativa), proporcionou o maior ganho para capacidade de expansão (8,15%) e ganho elevado para RG (24,29 %). Sendo assim, com base neste peso selecionaram-se os 38 genótipos superiores para recombinação e são esperados os supracitados ganhos no primeiro ciclo de seleção da população de milho-pipoca "Iva".

Palavras-chave: capacidade de expansão; parâmetros genéticos; índice de seleção; *Zea mays* L. var. *everta*

Introduction

Popcorn (*Zea mays* L. var. *Everta*) is a very popular food among the Brazilian population. However, its production is still far below the demand potential mainly due to the limitation of hybrid seeds and varieties of high quality, what pushing for the import of seeds (Freitas et al., 2013; Vieira et al., 2017). In this scenario, the development and launch of new popcorn cultivars are fundamental to reducing the dependence on genotypes from foreign countries, as well as supplying the demand of domestic producers and consumers (Guimarães et al., 2018).

Recurrent selection is considered an important strategy to obtain improved varieties; the BRS-Angela popcorn variety from Embrapa/CNPMS (Pacheco et al., 2001) and the UENF 14 variety from the State University Northern Fluminense Darcy Ribeiro (Amaral Júnior et al., 2013) are good examples of this strategy. This selection strategy aims to obtain improved varieties by gradually increasing the frequency of favorable alleles of the most important commercial traits, keeping the genetic variability of the improving population (Hallauer et al., 2010; Amaral Júnior et al., 2013).

The Federal University of Cariri - UFCA has developed an intrapopulation recurrent selection program with popcorn in order to produce and provide commercial varieties with high agronomic potential and adapted to the edaphoclimatic conditions of the southern region of the state of Ceará. Popcorn has a great potential to be exploited in the Cariri region of Ceará, mainly in the context of family farming, considering that this crops comes to be an incentive to the diversification of agricultural activities, providing extra income to small producers.

However, the main difficulty found in the improvement of this crop is related to achieving simultaneous gains for the two main characteristics of economic value, namely, grain yield and expansion capacity, because they are negatively correlated (Rangel et al., 2011; Cabral et al., 2016). To minimize the deleterious effects of this correlated response and increase the accuracy of the selection of genotypes that simultaneously meet both desired characteristics (productivity and expansion capacity), a viable tool is the use of selection indices (Vieira et al., 2017).

Selection indices represent a multivariate technique that allows generating a genotypic aggregate on which selection acts and that works as an additional character resulting from the combination of certain characteristics chosen by the breeder on which simultaneous selection can be done. It is possible, therefore, to separate superior genotypes for a set of characters regardless of the existence or not of correlations between characteristics (Amaral Júnior et al., 2010; Cruz et al., 2014). These genetic-statistical tools are able to identify in a fast and efficient way the genotypes that will allow the best gains with the selection, being consequently more suitable for breeding purposes (Freitas Junior et al., 2009).

The present work aimed to estimate the genetic gain in the first cycle of intrapopulation recurrent selection in

complete sib families of popcorn, through selection indices, for the main characteristics of commercial interest with emphasis on grain yield and expansion capacity.

Material and Methods

The method of recurrent selection among full-sib families of was employed in the "Iva" popcorn population, belonging to the germplasm bank of the Federal University of Cariri - UFCA. Two hundred and ten full-sib families were obtained, being these the result of manually controlled crosses carried out in 2013 in the Agrarian Sciences and Biodiversity Center of the Federal University of Cariri (CCAB/UFCA), in the municipality of Crato, CE, Brazil.

The 210 progenies were evaluated in two sites: in the city of Granjeiro, CE (6° 53'18"S, 39°13'04"W), where a hot, mild semi-arid tropical climate predominates, with average temperature and rainfall of 25 °C and 1,236.6 mm per year, respectively; and in the CCAB/UFCA, in the municipality of Crato, CE (7°14'03"S, 39°24'34"W), where the predominant climate is also hot tropical, mild semi-arid, with an average temperature and annual rainfall of 25 °C and 1090.9 mm, respectively (IPECE, 2014).

A randomized block design in 'sets' was used. Seven 'sets' with two replicates were used, in which each set contained 30 full-sib families. The experimental plots consisted of single rows of 5.00 m in length, spacing of 1.00 m between rows and 0.20 m between plants, resulting in 50,000 plants ha⁻¹. Three seeds were sown per pit to a depth of 0.05 m and thinning was performed at the 21st day after emergence, leaving one plant per pit. Fertilization at planting was performed according to soil analysis. Top dressing was performed at the 30th day after planting. Crop arrangements were made when necessary, in accordance with the recommendations for this crop.

For the purpose of evaluation, plant height (PH) was measured in meters from the ground level to the insertion of the flag leaf; measurements were made in five competitive plants. Corncob height (CH) expressed and meter, obtained by the measurement of the distance from the soil level to the base of the insertion of the first corncob in five competitive plants in the phenological stage of grain filling. At the time of harvest, the final plant stand (NP) was obtained by the number of plants in the plot.

After the harvest, the mass of corncob with grains (CW) was obtained by weighing the corncobs without straws, in kg ha⁻¹. Grain yield (GY) was determined by weighing the grains after removal of the cob, expressed in kg plot⁻¹ and later transformed to kg ha⁻¹. Expansion capacity (EC) was determined in the laboratory using a Midea-model MW30EL2VW microwaves; the evaluation was made based on the relation mL g⁻¹, that is, the volume of popcorn in a 2,000 mL beaker in relation to the mass of 30 g of kernels popped at a temperature of 270 °C for a time of three minutes with two sub-samples in each plot.

The data were submitted to analysis of joint variance, according to the following statistical model:

$$Y_{ijkl} = \mu + A_i + S_j + AS_{ij} + \frac{R}{AS_{ijk}} + \frac{F}{S_{ji}} + \frac{AF}{S_{ijl}} + \varepsilon_{ijkl}$$

where: Y_{ijkl} - is the mean phenotypic value of the plot; μ - is the mean; A_i - is the fixed effect of the i -th environment; S_j - is the effect of the j -th "set"; AS_{ij} - is the effect of interaction between environments and sets; R/AS_{ijk} - is the effect of the k -th repetition within the interaction between the i -th environment and the j -th "set"; F/S_{ji} - is the random effect of the i -th family within the j -th "set"; AF/S_{ijl} - is the effect of the interaction between environments and families within the j -th "set"; and ε_{ijkl} - is the experimental error. The sources of variation, with the exception of environment, were considered of random nature. The SAS software (2003) was used for the statistical analysis.

Estimates of variance components were obtained based on expected mean squares. Genotypic variance between families was expressed as:

$$\sigma_g^2 = \frac{\frac{QMF}{S} - QMR}{ar}$$

where: QMF/S - mean square of families within sets; QMR - mean square of the residue; a - number of environment; and r - number of repetition. Residual and phenotypic variances between families were expressed, respectively, as:

$$\sigma_r^2 = \frac{QMR}{ar}$$

and

$$\sigma_f^2 = \frac{QMF}{ar}$$

Heritability based on the mean of families was estimated as:

$$h^2 = \frac{\sigma_g^2}{\sigma_f^2}$$

The coefficient of percentage of genetic variation and the variation index were obtained according to Cruz et al. (2014), using the following equations respectively:

$$CV_g = 100 \sqrt{\frac{\sigma_g^2}{\bar{x}}}$$

and

$$\hat{I}_v = \frac{CV_g}{CV_e}$$

Estimates of the predicted gain per selection, using selection indices, were based on the means of the environments. Predictions of gains per selection were obtained according to the indices of Mulamba & Mock (1978) and Smith (1936) and Hazel (1943).

The index provided by Mulamba & Mock (1978) hierarchizes the genotypes initially for each characteristic, by assigning higher absolute values to those of better performance. The values attributed to each characteristic are summed at the end, and the sum of ranks indicates the classification of genotypes (Cruz et al., 2014). The index of Smith (1936) and Hazel (1943) are based on the solution of the matrix system $b = P^{-1}Ga$, where b is the vector of dimension 6×1 of the weighting coefficients of the index to be estimated; P^{-1} is the inverse of the 6×6 matrix of phenotypic variance and covariance between characteristics; G is a 6×6 of genetic variance and covariance between characteristics; and a is a 6×1 vector of economic weights.

These selection indices were used to select the 38 superior full-sib families of the first cycle, adopting as economic weights those suggested by Cruz et al. (2014): coefficient of genetic variation (CV_g); genetic standard deviation (SD_g); heritability (h^2); index of variation (I_v) and weights assigned by attempts (WA) for each characteristic. The latter were obtained after several attempts, applying the highest weights to the characteristics of greater relevance for popcorn, distributed as follows: 1, 1, 1, 15, 25 and 15 respectively, for PH (height of the plant), CH (corn cob height), NP (number of plants), CW (weight of corn cob with grains), GY (grain yield) and EC (expansion capacity). The Genes software was used to perform these statistical analyses (Cruz, 2013).

Results and Discussion

Significant differences ($p \leq 0.01$) for all the characteristics (Table 1) were observed for the source of variation environment (E), showing that the environments of Crato and Granjeiro were distinct enough to favor differences between the characteristics; these are, therefore, representative for evaluation of progenies in recurrent selection (Table 1).

Regarding the sources of variation "set" and "environment x set interaction" (E x S), the mean squares were significant ($p \leq 0.05$) for all the characteristics (Table 1). This result strongly indicates the importance and need of the use of a block design with division in 'sets' because the absence of this division could produce variations that cause loss of accuracy in the experiments (Rangel et al., 2011 ; Ribeiro et al., 2012).

For the source of variation Families within "set" (F/S), it was observed that all the characteristics evaluated had a highly significant effect ($p < 0.01$), except NP (Table 1). This result shows the existence of genetic variability to be explored in this cycle and in future cycles, to favor the progress in the selective process of superior families.

The significance of PH and EC for the interaction environment "versus" family within set reveals that for

Table 1. Mean squares, means and coefficients of experimental variation of six characteristics evaluated in two environments in 210 full-sib families of popcorn in the first cycle of intrapopulation recurrent selection.

FV	GL	Mean squares					
		PH	CH	NP	CW	GY	EC
Environment (E)	1	58.70**	16.01**	838.00**	63055510.72**	49986721.23**	24.19**
Set (S)	6	1.51**	0.69**	8.47*	7528262.74**	6902236.22**	137.93**
E x S	6	0.64**	0.22**	6.25*	91097.83*	221424.51**	5.58**
Rep (R)/E x S	14	0.30**	0.12**	8.03*	16499.10 ^{ns}	16499.33 ^{ns}	0.49 ^{ns}
Family (F)/ S	203	0.06**	0.03**	3.80 ^{ns}	690171.30**	686399.30**	31.54**
(E x F)/ S	203	0.03*	0.01 ^{ns}	3.80 ^{ns}	8859.21 ^{ns}	9066.50 ^{ns}	34.00**
Resíduo	406	0.02	0.01	3.45	20331.80	20331.80	1.08
Mean		1.4	0.7	21.79	2167.02	1956.69	22.75
CVe (%)		10.55	13.50	8.52	6.58	7.29	4.57

PH: plant height in m; CH: height of insertion of the first corn cob in m; NP: final plant stand; CW: mass of corn cobs with grains in kg ha⁻¹; GY: grain yield in kg ha⁻¹; and EC: grain expansion capacity in mL g⁻¹; **: significant (p ≤ 0.01) in the F test; *: significant (p ≤ 0.05) in the F test; ^{ns}: non-significant.

these characteristics, the full-sib families presented irregular performance in relation to the edaphoclimatic changes of the environments (Table 1). Rangel et al. (2011) evaluated a fifth-cycle population of intrapopulation recurrent selection in full-sib families and also found a significant effect for EC. The influence of the environment on the expansion capacity of popcorn can be explained by the fact that not all the genes that contribute to the hardness of the endosperm contribute to the capacity of expansion. In view of this aspect, EC can present an inconsistent behavior in different environments (Robbins & Ashman, 1984; Cabral et al., 2016).

As for experimental accuracy indicated by the experimental coefficient of variation (CVe%), it was observed that for all the characteristics, the estimates of this parameter were low (CVe% < 15%), showing good control of environmental conditions and good suitability to the experimental design.

Knowledge about estimates of genetic parameters (Table 2) allows breeders to generate useful information about the different characteristics evaluated in the population with which they work, thus guiding the best selection strategy and the prediction of breeding programs (Cruz et al., 2014).

When genotypic variance estimates (σ_g^2) express significant and non-zero values, this indicates the existence of genetic variability in the population analyzed. Furthermore, it is desirable that values of residual variance (σ_r^2) be low so that the selective accuracy of superior progenies may be maximized. It is, therefore, evident in this population of first recurrent selection cycle that there is a good chance

of selective success, especially when performed under the characteristics of NP, CW, GY and EC, considering that they exhibited high estimates of σ_g^2 larger than the estimates of σ_r^2 (Table 2).

Inheritability expresses the reliability of the phenotypic value as a guide to the genetic value, or degree of correspondence between phenotypic value and genetic value. In other words, inheritability reveals the reliability of the phenotypic value measured to predict the true genotypic value (Cruz et al. 2014). In general, estimates of heritability varied from 60.03 to 97.05% for PH and CH, respectively. It was observed that for the characteristics of greater economic importance for popcorn, GY and EC, heritability estimates were of high magnitudes, 97.04 and 96.57, respectively (Table 2). Therefore, taking into account these magnitudes of h^2/x , the recurrent intrapopulation selection procedure is considered a suitable strategy to obtain greater gains in view of the higher concentration of favorable alleles in the population.

Guimarães et al. (2018) evaluated full-sib families from eight recurrent intrapopulation selection cycles in popcorn and obtained estimates of heritability lower than those found in the present study, with results of 47 and 44% for grain yield and expansion capacity, respectively.

The coefficient of genetic variation (CV_g) quantifies the magnitude of the genetic variation available for selection and, therefore, high values are desirable. It should be noted that all characteristics showed high values of CV_g , especially corn cob weight (CW), grain yield (GY) and expansion capacity

Table 2. Estimates of genotypic variance (σ_g^2), phenotypic variance (σ_f^2), residual variance (σ_r^2), heritability based on the mean of families (h^2/x), coefficient of genetic variation (CV_g) and index of variation (Iv) of the first cycle of recurrent intrapopulation selection in full-sib families of popcorn.

Characteristics	$\hat{\sigma}_g^2$	$\hat{\sigma}_f^2$	$\hat{\sigma}_r^2$	\hat{h}_x^2	\widehat{CV}_g	\widehat{Iv}
PH	0.008	0.014	0.022	60.03	6.47	0.61
CH	0.004	0.006	0.009	63.25	8.86	0.66
NP	4.883	5.207	1.297	93.77	10.93	1.94
CW	167,458.95	172,542.83	20,335.50	97.05	18.88	2.87
GY	166,516.88	171,599.83	20,331.80	97.04	20.85	2.86
EC	7.615	7.886	1.083	96.57	12.13	2.65

PH: plant height in m; CH: height of insertion of the first corn cob in m; NP: final plant stand; CW: mass of corn cobs with grains in kg ha⁻¹; GY: grain yield in kg ha⁻¹; and EC: grain expansion capacity in mL g⁻¹.

(EC) with estimates of 18.88, 20.85 and 12.13% respectively, indicating that a high fraction of the genetic variances was derived from the total phenotypic variation (Table 2). In view of such observations, it can be said that these values reveal a good chance of success in breeding programs that use this population that aim at the selection of these characteristics (Freitas et al., 2013; Ribeiro et al., 2016).

The index of variation (lv) is an important parameter because it offers a real idea of the situation of each characteristic for the breeding program. This index refers to the ratio CV_g/CV_e , and it is desirable that this estimate reaches values close to or greater than one (Vencovsky, 1987; Cruz et al., 2014). It was observed that the NP, CW, GY and EC presented values $lv > 1$, what indicates that for these characteristics, there was a greater predominance of genetic effects than environmental effects, denoting a more favorable condition for improvement. Thus, simple and easy-to-execute breeding methods would be sufficient to obtain satisfactory gains. However, the characteristics PH and CH showed values of $lv < 1$, with estimates of 0.61 and 0.66, respectively. Nevertheless, satisfactory gains in progeny selection based on these characteristics can be expected in view of the fact that they presented estimates of lv of moderate magnitudes. In this way, it was observed that all evaluated characteristics presented favorable values, indicating that the genotypes evaluated are promising, allowing future gains in the selective processes.

In popcorn improvement, the prediction of gains based on selection indices is necessary to search an ideal ideotype or genotype. In order to do this, the goal is always to seek gains in more than one characteristic, particularly with respect to the selection of families that are more productive and have greater expansion capacity (Amaral Júnior et al., 2013).

In the prediction of genetic gains of the characteristics for the selection of superior full-sib families (Table 3), we observed the percentage gains predicted for the selection index of Mulamba & Mock (1978), and observed that for all the economic weights used with exception of the standard deviation genotype (SDg), positive gains for all evaluated characteristics were revealed. When using SDg as an economic weight, it was observed that this SDg yielded the highest predicted gains for plant height (PH) (5.83%), corncob height (CH) (7.15%), corncob weight (CW) (30.16%) and grain yield (GY) (33.37%). However, this estimator cannot be used due to the negative gain (-5.74%) expressed for expansion capacity (EC), which is undesirable because the goal was to select families that have simultaneously high grain yield and good expansion capacity (Table 3).

When using the economic weights CVg, lv and h^2 , it was observed that the PH and CH presented high positive predicted gains (Table 3). However, it should be noted that positive gains for these two traits are not always desirable, since plants with larger and taller corncobs are more susceptible to breaking and bedding, in addition to

Table 3. Estimates of percentage gains based on the selection differential, by simultaneous selection of fifteen characteristics in the first cycle of recurrent intrapopulation selection in full-sib families of popcorn.

Characteristics	CVg	SDg	lv	h^2	WA
Mulamba & Mock					
PH	5.17	5.83	4.43	4.76	3.47
CH	7.11	7.15	5.72	6.03	4.99
NP	10.02	11.57	13.61	12.99	13.99
CW	17.26	30.16	26.27	25.76	21.73
GY	18.85	33.37	29.45	28.65	24.29
EC	0.14	-5.74	2.52	1.28	8.15
Smith & Hazel					
PH	4.09	4.09	4.09	5.83	4.09
CH	5.3	5.3	5.3	7.15	5.3
NP	10.99	10.99	10.99	11.57	10.99
CW	29.47	29.47	29.47	30.16	29.47
GY	32.59	32.59	32.59	33.37	32.59
EC	-5.56	-5.56	-5.56	-5.74	-5.56

Economic weights used in selection indices, CVg = coefficient of genetic variation; SDg = genetic standard deviation; lv = index of variation (CVg/CVe ratio); h^2 = heritability; and WA = weights assigned by attempts (1, 1, 1, 15, 25, 15).

PH: mean plant height in m; CH: mean height of insertion of the first corncob in m; NP: final plant stand; CW: mass of corncobs with grains; GY: grain yield; and EC: grain expansion capacity.

hindering the harvesting process. Thus, cultivars with these characteristics have their recommendations restricted to sites with high intensity of winds; in this case, plants with a size below 2.00 m are more suitable (Amaral Júnior et al., 2010; Freitas et al., 2013).

The characteristics PH and CH, their gains were not so high (3.47 and 4.99%), although they were positive gains. In addition, NP, CW and GY presented high and positive predicted gains, which are interesting in a population because as the population presents greater corncob weight of and, consequently, higher grain yield. This economic weight was also the one that caused the greatest gain in expansion capacity (8.15%) (Table 3). In the case of the index of Mulamba & Mock (1978), the weights attributed by attempts (WA) allowed the best gains, mainly for the two characteristics of greater interest in popcorn from a selective point of view (GY and EC). Similar results with the use of weights assigned by attempts (WA) were also found by Arnhold & Viana (2007), Freitas Júnior et al. (2009), Rangel et al. (2011), Ribeiro et al. (2012), Freitas et al. (2013) and Guimarães et al. (2018).

On the other hand, the selection index of Smith (1936) and Hazel (1943) did not allow to predict simultaneous gains for the two main characteristics (EC and GY), because all economic weights presented negative values for EC. Yet, the highest gains for GY were predicted by this index (above 32%) for all economic weights evaluated (Table 3).

It was noted that for all the economic weights used (CVg, DPg, IV and PA), the predicted gains were the same for all the characteristics, even assigning weights by attempts of different magnitudes. Thus, this index did not allow discrimination of the values obtained by the economic

weights, demonstrating that there was not enough discrepancy to cause changes in the gains (Table 3). Freitas Júnior et al. (2009) estimated the predicted gains through selection indices in the population of UNB-2U popcorn under recurrent selection and found similar results to this study, with similar predicted gains in all characteristics by the selection index of Smith (1936) and Hazel (1943).

Therefore, for the present study, the "sum of ranks" index of Mulamba & Mock (1978) based on weights assigned by attempts (WA) was the most appropriate method for the selection of 40 full-sib families (Table 4) that were reliably superior for the recombination of the evaluated

Table 4. Means of the 38 full-sib families selected based on the economic weight WA by the index of Mulamba and Mock (1978), to compose the first cycle of recurrent selection. Crato, CE and Granjeiro, CE, 2014.

Families	Mean characteristics					
	PH	CH	NP	CW	GY	EC
1	1.31	0.66	19.50	2682.50	2415.00	20.75
10	1.48	0.77	24.25	2037.00	1769.50	21.43
34	1.58	0.81	24.00	2413.50	2171.00	24.93
35	1.36	0.64	21.75	2359.50	2117.00	27.86
37	1.44	0.73	23.25	2845.50	2615.50	19.73
41	1.38	0.69	20.50	3125.00	2895.00	20.58
46	1.42	0.67	21.75	2684.00	2456.50	22.51
47	1.39	0.66	21.75	2265.50	2038.00	25.33
48	1.51	0.76	22.50	2517.50	2290.00	24.99
56	1.33	0.80	20.00	2468.50	2216.00	23.55
63	1.65	0.74	22.00	2451.00	2216.00	24.57
72	1.51	0.72	21.00	2451.00	2226.00	22.61
73	1.29	0.60	23.50	2428.50	2202.25	28.13
77	1.31	0.55	21.00	2599.50	2372.00	22.73
80	1.43	0.63	22.25	2716.50	2489.00	21.65
82	1.55	0.79	23.75	2721.00	2526.00	18.44
91	1.56	0.80	21.50	3130.50	2933.00	22.35
99	1.51	0.81	22.00	2442.00	2244.50	26.16
100	1.56	0.75	21.75	2500.50	2303.00	24.57
102	1.32	0.68	23.25	2757.00	2559.50	21.15
109	1.50	0.73	21.75	2532.00	2334.50	24.66
116	1.54	0.86	22.25	2896.50	2689.00	24.78
118	1.48	0.76	22.50	2545.50	2338.00	23.87
122	1.63	0.82	21.00	2379.00	2171.50	22.50
126	1.61	0.84	22.00	2686.50	2479.00	25.17
130	1.54	0.79	21.75	2322.00	2114.50	25.17
137	1.64	0.87	23.25	2416.50	2209.00	22.73
149	1.59	0.90	22.25	3271.50	3064.00	23.11
151	1.36	0.68	22.25	2740.50	2533.00	25.10
154	1.30	0.68	23.25	2542.50	2335.00	25.37
156	1.48	0.67	23.50	2785.50	2578.00	28.87
157	1.58	0.80	22.75	2974.50	2767.00	23.33
163	1.40	0.69	22.00	2740.50	2576.50	20.31
171	1.41	0.73	23.25	2830.50	2666.50	21.53
172	1.49	0.80	22.25	2754.00	2590.00	24.17
173	1.58	0.74	20.50	2308.50	2144.50	28.84
174	1.26	0.57	21.25	2452.50	2287.00	26.08
205	1.26	0.57	21.25	2452.50	2287.00	26.08
Média	1.46	0.73	22.11	2611.24	2400.49	23.83

PH: mean plant height in m; CH: mean height of insertion of the first corncob in m; NP: final plant stand; CW: mass of corncobs with grains; GY: grain yield; and EC: grain expansion capacity.

traits, mainly GY and EC, favoring consistent gains for the next cycle of recurrent selection. This allowed superior and better distributed gains among the characteristics. A number of authors (Vilarinho et al., 2003; Arnhold & Viana, 2007; Freitas Júnior et al., 2009; Rangel et al., 2011; Freitas et al., 2013; Ribeiro et al., 2016; Guimarães et al., 2018) have also reported the effectiveness of the selection index of Mulamba & Mock (1978) to obtain higher gains, mainly for the two characteristics of greater economic value, i.e. grain yield and expansion capacity, in popcorn.

Conclusion

Gains of 24.9% for grain yield and 8.15% for expansion capacity are expected in the first selection cycle of the "Iva" popcorn population when the index of Mulamba & Mock (1978) is used, based on the economic weight attributed by attempts.

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