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Five cycles of intrapopulation recurrent selection in half-sib progenies of fresh corn

Cinco ciclos de seleção recorrente intrapopulacional em progênies de meio-irmãos de milho fresco

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ABSTRACT - Fresh corn is a highly appreciated vegetable in Brazil; this crop has high added value and profitability when compared to dry corn. Despite the consumer market demand for quality, cultivars are not launched every crop season and there is a small number of cultivars available to growers. This denotes a need for breeding programs focused on generating information and genotypes that can occupy this market niche. The objective of this work was to evaluate the progress of five cycles of intrapopulation recurrent selection in half-sib progenies of fresh corn, in the southwest region of Goiás. A randomized block experimental design was used, with evaluation of 64 progenies of corn half-sib progenies and selection intensity of 30% per cycle, with three replications, in the 2011-2012, 2013-2014, 2015-2016, 2017-2018, and 2020-2021 summer crop seasons. The half-sib progenies of fresh corn exhibited genetic variability through intrapopulation recurrent selection in the different selection cycles, which is still promising for further selections after five cycles, with evaluation of 64 progenies per cycle. The base population from crossings between hybrids for tropical and temperate climates showed to be promising for increasing the genetic base of fresh corn populations, with satisfactory gains over the five cycles, presenting mean heritability between the cycles of approximately 78.9% for relative chlorophyll index, 62.2% for plant height, 75.1% for ear insertion height, 70% for ear diameter, 56.6% for ear length, 71.4% for unhusked ear yield, and 71% for marketable ear yield.

Keywords: *Zea mays* L. Genetic variability. Unhusked ears. Marketable ears. Heritability.

RESUMO - O milho fresco é uma hortaliça muito apreciada pelos brasileiros e, além disso, possui alto valor agregado e maior lucratividade, quando comparado aos grãos secos. O mercado consumidor apesar de exigente na qualidade, não é abastecido com novas cultivares a cada safra e com um número ínfimo sendo disponível aos produtores. Assim, existe a necessidade da criação de programas de melhoramento, com o intuito de gerar informações e genótipos capazes de suprir esse nicho de mercado. O objetivo do estudo foi avaliar o progresso da seleção em progênies de meios-irmãos de milho fresco, em cinco ciclos de seleção recorrente intrapopulacional, na região sudoeste de Goiás. O delineamento experimental utilizado foi o de blocos casualizados, com a avaliação de 64 progênies de meios-irmãos e intensidade de seleção de 30% por ciclo, com três repetições, em diferentes safras de verão (2011-2012, 2013-2014, 2015-2016, 2017-2018 e 2020-2021). As progênies de famílias de meios-irmãos de milho fresco apresentaram variabilidade genética por meio de seleção recorrente intrapopulacional nos diferentes ciclos de seleção, com avaliação de 64 progênies por ciclo. A população base de cruzamentos entre híbridos para climas tropicais e temperados mostrou-se promissora para aumentar a base genética de populações de milho fresco, com ganhos satisfatórios ao longo dos cinco ciclos, com herdabilidade média de aproximadamente 78,9% para o índice relativo de clorofila, 62,2% para altura de planta, 75% para inserção da espiga, 70% para diâmetro da espiga, 56,6% para comprimento da espiga, 71,4% para espigas empalhadas e 71% para espigas comerciais entre os ciclos.

Palavras-chave: *Zea mays* L. Variabilidade genética. Espigas empalhadas. Espigas comerciais. Herdabilidade.

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INTRODUCTION

Corn is among the main cereals grown throughout the world and presents a high socioeconomic importance due to its diversity and versatility of use, which is connected to industrial raw materials and animal and human feed. Corn is consumed as dry and immature grains. Immature grains are a valuable addition to contemporaneous diets; it is an alternative food rich in folate and a source of vitamins, even after being cooked (CANDIDO et al., 2020; ISLAM et al., 2021). The fresh corn market in Brazil yielded R$ (BRL) 201 million in 2020, the Central-West region represented 12.6%, and the state of Goiás was responsible for 11.1% of this market, which has been growing in the latest crop seasons (CONAB, 2021), with favorable prices to growers, which are almost twice as high as the price in the Southeast region of the country in most months (CONAB, 2023). This is a specific market niche, based mainly on small and medium growers, family farmers, or low-investment farmers, and is seen as an attractive agricultural activity due to the high added value to the product.

Currently, there is only one corn cultivar focused on fresh consumption in

the market, the BRS3046 (conventional), among the 98 corn cultivars available in the 2020-2021 crop season; four cultivars available for this niche were excluded and the number of cultivars in relation to previous crop season decreased approximately 45% (PEREIRA FILHO; BORGHI, 2021), which restricts this crop. Therefore, the development of improved populations, hybrids, and varieties with open pollination are essential to meet the demands of growers and consumers and, generate information and quality genotypes for fresh consumption (RESENDE et al., 2021).

Therefore, the recurrent selection method is a viable option by selecting the best progenies over several cycles to obtain successive gains in each cycle without depleting the genetic variability of the population (HALLAUER; CARENA; MIRANDA FILHO, 2010). Intrapopulation recurrent selection in corn half-sib progenies is among the strategies used for this purpose, due to its easy conduction, applicability, and high efficiency in obtaining genetic gains, as found for grain corn (SHEIKH et al., 2019), which includes works focused on resistance to corn weevil (*Sitophilus zeamais*) (LÓPEZ-CASTILLO et al., 2018), popcorn (GUIMARÃES et al., 2019), and fresh corn (RESENDE et al., 2021). In this context, the objective of this work was to evaluate the progress of five cycles of intrapopulation recurrent selection in half-sib progenies of fresh corn grown in the southwest region of Goiás.

MATERIAL AND METHODS

The experiment was conducted at the Universidade Estadual de Goiás (UEG), in Ipameri, GO, Brazil, during the summer, after five selection cycles. The corn population used for the formation of progenies was from the MV-003 population, obtained through complex crossing between the imported hybrids CN19-50 and CN 23-50, which are sweet corn hybrids (*susu*), and the double experimental hybrid HD17 (*SuSu*) of the UEG plant breeding program (MELHORVE), which present more adequate characteristics to the national market and higher starch contents (*SuSu*), as shown by Resende et al. (2021). The progenies were pre-selected and then subjected to five selection cycles, using intrapopulation recurrent selection of half-sib progenies. Sixty -four progenies of corn half-sib progenies were evaluated; the experiments were conducted between October and November, during the rainy season, in the 2011-2012, 2013-2014, 2015-2016, 2017-2018, and 2020-20/21 crop seasons, under a randomized block design, with three replications and using a selection intensity of 30%.

Conventional soil preparation was used, with one plowing and two harrowing, using and a cultivator to open furrows. The experimental plots consisted of two four-meter rows, with three plants per meter and spacing between rows of 0.5 m (60.000 plants ha^{-1}). A thinning was carried out at 21 days after emergence to maintain the number of plants. Soil fertilizer application at sowing was carried out using 20 kg ha^{-1} of N (urea), 120 kg ha^{-1} of P_2O_5 (triple superphosphate), and 90 kg ha^{-1} of K_2O (potassium chloride), and 100 kg ha^{-1} of N (urea) as topdressing, which were placed next to the rows at the V_3 stage, at approximately 30 days after sowing, according to Pereira Filho (2002), for a yield of ears with husks between 15 and 17 Mg ha^{-1}. Cultural practices consisted of manual weeding for control of weeds and application of phytosanitary products, including chlorantraniliprole 100 gr L^{-1} + lambda-cyhalothrin 50 gr L^{-1} (Ampligo®) at rate of 150 ml ha^{-1} to control *Spodoptera frugiperda* caterpillars.

The following variables evaluated were measured according to Resende et al. (2021): RCI - relative chlorophyll index (falker); PH - plant height (cm); EIH - ear insertion height (cm); ED - ear diameter (cm); EL - ear length (cm); UEY - unhusked ear yield (kg ha^{-1}); and MEY - marketable ear yield (kg ha^{-1}). The harvest was carried out manually as the ears reached the milky grain point, the R_3 stage, i.e., when the grains are with 70% to 80% water content, which is the ideal point for the marketing, by harvesting five representative ears at approximately 90 days after sowing, and the other part of the plot after the plants reach physiological maturation (R_6).

The experiments were analyzed separately, according to the statistical model:

$$Y_{ij} = m + p_i + b_j + \varepsilon_{(ij)}$$

Where: Y_{ij} refers to progenies i in block j; m is the overall average; p_i is the effect of the i^{th} progenies; b_j is the effect of j^{th} block; and $\varepsilon_{(ij)}$ is the experimental error. Genotypic and phenotypic parameters were then estimated using the procedure proposed by Cruz, Regazzi and Carneiro (2012), and regression analysis, with the aid of the program Genes (CRUZ, 2016).

RESULTS AND DISCUSSION

The half-sib progenies of corn presented genetic variability in the different selection cycles for all characteristics evaluated ($p< 0.01$), except for plant height in the third selection cycle (Table 1). In addition, the experimental precision was, in general, considered intermediate or low, according to the scale used by Fritsche-Neto et al. (2012). Plant heights (3.8% to 5.8%), ear heights (4.4% to 8.3%), and ear diameters (5.4% to 11.9%) were considered adequate for experiments with corn. Fritsche-Neto et al. (2012) found that these characteristics are less affected by the environment, except in the cycle 2, when a dry spell occurred at the vegetative (V_3 – V_5) and reproduction (R_1 – R_2) stages and interfered with the variability of progenies and the CV (%), mainly for yield.

The relative chlorophyll index (RCI) gradually increased over the selection cycles, with an increase of 17% (9.33 Falker units) throughout the cycles, presenting a high

heritability (h^2), above 74%, which indicates higher photosynthesis and probably higher production of photoassimilates every cycle (Figure 1A). According to Ghimire, Timsina and Nepal (2015), increases in chlorophyll is advantageous for corn plants, as yield is directly connected to these indexes and moderately correlated with increases in number of grains per row, number of rows per ear, and ear weight, which are important characteristics for the market.

Table 1. Analysis of variance of relative chlorophyll index (RCI), plant height (PH), ear insertion height (EIH), ear diameter (ED), ear length (EL), unhusked ear yield (UEY), and marketable ear yield (MEY) in five selection cycles of progenies of half-sib progenies of corn intended for fresh production.

	Source of Variation	Selections (crop seasons)				
		2011-2012	2013-2014	2015-2016	2017-2018	2020-2021
		Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5
RCI	Progenies	39.4**	34.4**	30.5**	53.2**	57.2**
	Blocks	1.2	18.1	257.0	277.7	271.3
	Error	3.4	13.1	7.8	12.6	12.3
	CV (%)	3.9	7.5	5.6	7.2	7.0
PH	Progenies	353.2**	386.2**	143.9n.s.	327.9**	328.4**
	Blocks	214.6	7357.9	6383.5	2506.2	870.4
	Error	47.9	70.2	151.2	69.6	119.0
	CV (%)	3.8	4.4	5.8	4.2	5.0
EIH	Progenies	340.3**	171.7**	112.9**	300.0**	160.8**
	Blocks	11.9	592.3	1766.4	520.8	745.2
	Error	26.2	24.5	33.9	65.2	67.8
	CV (%)	5.4	5.1	4.4	8.3	8.3
ED	Progenies	3.3**	3.2**	0.8**	3.2**	3.4**
	Blocks	8.2	9.5	31.6	1.0	0.2
	Error	0.4	0.3	0.2	0.2	0.2
	CV (%)	11.9	8.7	9.0	6.6	5.4
EL	Progenies	8.7**	8.0**	6.7**	6.4**	6.9**
	Blocks	172.2	21.0	24.1	24.7	11.5
	Error	5.0	5.5	1.4	2.5	2.2
	CV (%)	13.4	13.1	6.9	8.4	7.2
UEY	Progenies	963540.0**	2814162.8**	2754614.2**	2764031.3**	2270710.3**
	Blocks	1253239.1	30384469.0	2880765.3	1081989.7	6387823.2
	Error	108062.0	1513911.8	544729.3	620177.0	487345.3
	CV (%)	7.1	19.9	13.7	11.0	6.7
MEY	Progenies	1041324.1**	1846941.9**	1377390.3**	932628.3**	791323.4**
	Blocks	413171.9	8808877.6	3115216.3	1723022.6	1874256.1
	Error	109786.0	524662.1	288314.5	410435.8	214037.0
	CV (%)	8.6	15.2	19.5	10.4	5.5

** = highly significant, * = significant at 5% probability level, and n.s. = not significant by the F test; CV (%) = coefficient of variation.

Plant height (PH) and first ear insertion height (EIH) presented increases of 15.62 and 20.96%, respectively, after the five selection cycles, with high h^2 at the beginning of the breeding program and higher decreases at the fifth cycle (Figures 1B and 1C). PH was more affected by the dry spell than EIH, with decreases of 15% and 11.7% in h^2 from the 4th to the 5th cycle respectively, and possible height stabilizations at approximately 208 and 106 cm, respectively. This may be related to increases in temperature and low rainfall depths close to the reproductive stage, which affected several growers in the estate of Goiás (CONAB, 2021).

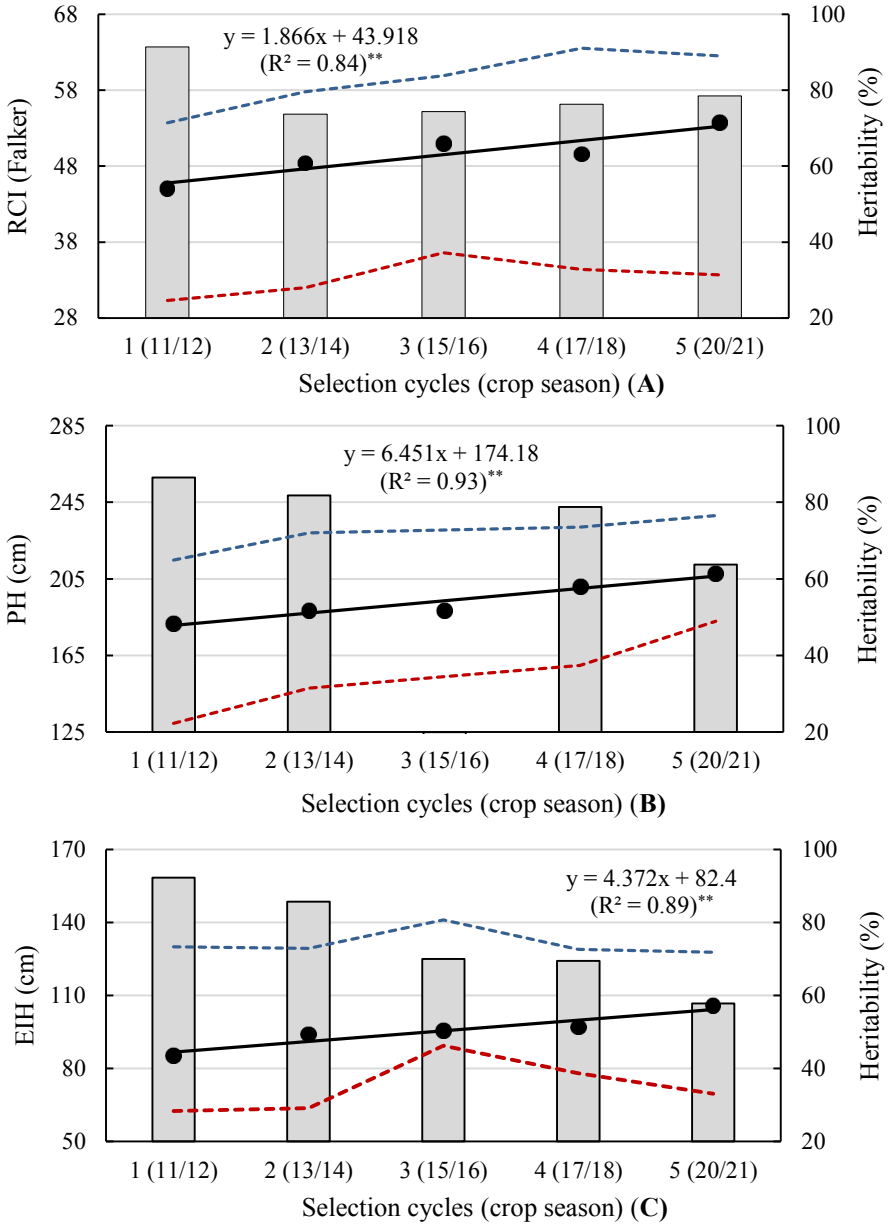

Figure 1. Mean (●), heritability (■), upper limit (---), and lower limit (---) of relative chlorophyll index (RCI), plant height (PH), and ear insertion height (EIH) over five selection cycles (2011-2012, 2013-2014, 2015-2016, 2017-2018, and 2020-2021) of evaluation of 64 progenies of corn half-sib progenies, focused on fresh corn production.

Silva et al. (2015) evaluated six corn hybrids intended for sweet corn production and found values of 190.4 (PH) and 117.3 cm (EIH); however, the population density used was 45,000 plants per hectare, which directly affect these variables. The purpose of the breeding program is to avoid tall plants, increase densification, and decrease susceptibility to lodging for increasing yield without losing quality, as also stated by Qureshi and Khalil (2019). The h^2 magnitude found for these heights in the fifth cycle were 63% and 58%, respectively, indicating the possibility of genetic gains, but lower, in the subsequent selections, which may hinder decreases in PH and EIH (Figures 1B and 1C). Rangel et al. (2011) evaluated 200 full-sibling progenies at the fifth selection cycle for popcorn corn production and found h^2 of 84.55% and 82.66% for ear and plant heights, respectively.

The mean ear diameter (ED) found was 4.9 cm in the first selection cycle and 6.1 cm in the fifth selection cycle, representing a mean increase of 0.24 cm for each selection cycle (Figure 2A). It occurred due to the high h^2 over the five selection cycles, which presented an estimated mean of 70%, favoring direct genetic gains for this characteristic. These results are interesting for fresh corn breeding programs, as consumers always prefer ears with large diameters and lengths (SILVA et al., 2015), mainly when they are marketed in trays or vacuum packaging. Ear length (EL) presented mean of 16.6 cm in the first selection cycle and 19.9 cm in the fifth cycle,

with a total gain of 20% after the five cycles (Figure 2B). The allelic combinations in the first cycles were not favorable, with low genetic variability expressed by h^2 and initially unsatisfactory gains. However, this characteristic was more affected in the cycle with dry spell, when the length presented the highest genetic variability, with possibility of higher gains and reaching more expressive values. When tropical and temperate cultivars are crossed, the genotypes formed present spike patterns that are not desirable in the market; this pattern is observed and maintained only after a few selections. Thus, the diameter is negatively affected when focusing on progenies with greater length. According to the results presented by Sajjad et al. (2020), this characteristic presents little variation in different environments and, even with depression by endogamy, decreases are not pronounced in S_1 and S_2 progenies, with mean values varying from 15.64 to 17.18 cm.

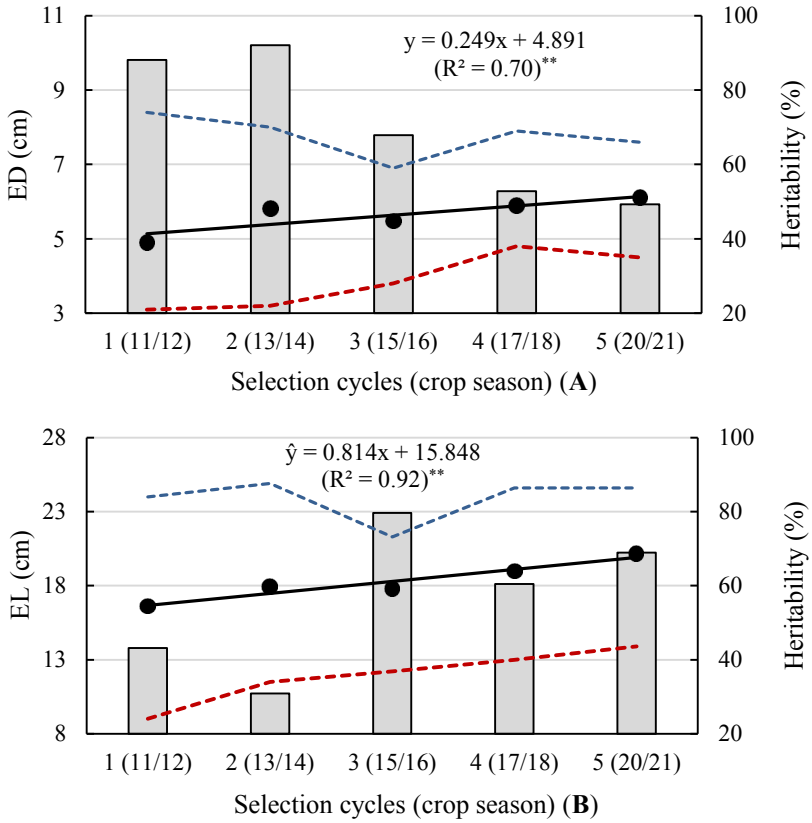

Figure 2. Mean (●), heritability (■), upper limit (---), and lower limit (---) of ear diameter (ED) and ear length (EL) over five selection cycles (2011-2012, 2013-2014, 2015-2016, 2017-2018, and 2020-20/21) of evaluation of 64 progenies of corn half-sib progenies focused on fresh corn production.

The evaluated progenies have high frequency of alleles of sweet corn and tend to have smaller diameters and longer lengths in their genetic base, as found by Özata (2019), who found values of 4.8 and 21.6 cm, respectively, for five cultivars in two sites, and by Stansluos, Öztürk and Kodaz (2020), who found 4.8 and 18.1 cm, respectively, for 11 cultivars in two crop seasons. These are similar values to those found for length in the 5th cycle and better than those found for ear diameter, indicating the potential of this population for development of varieties (Figures 2A and 2B).

Unhusked ear yield (UEY) is one of the most commercially interesting characteristics, as fresh corn is mostly marketed with husks and is importance for the logistics in this market. This variable increased between the first and fifth cycle at 1,348.4 kg ha^{-1} per selection cycle, resulting in an increase of 3.1-fold (9,965 kg ha^{-1}) in the fifth cycle, which represented a high and frequent mean gain over the cycles (Figure 3A). These values were well below those expected and the effect of alleles of the sweet corn hybrids, which were imported from the United States and intended for environments different from those used in the breeding program, caused lower initial capacity of ear formation and pollination, resulting in small ears and undesirable allelic combinations. This same condition is observed after straw removal (marketable ear yield), with more significant reductions in the last selection cycles (Figure 3B).

Kaymak and Ürüşan (2020) evaluated four sweet corn cultivars and found mean yield of approximately 14,575 kg ha^{-1} for ears with husks, in two crop seasons, and approximately 9,471 kg ha^{-1} for ears without husks. However,

considering that this is a perishable product and the quality should be prioritized, these values tend to be different between hybrids, locations, seasons of the year, and fertilizer applications, as reported by Almeida et al. (2020), who found values varying from 9,067 to 13,962 kg ha^{-1} for ears with husks, and 3,012 to 8,393 kg ha^{-1} for ears without husks. The initial crossing was between cultivars adequate for temperate and tropical climates, which increases variability, are more promising in different environments, and generate new allelic combinations, including those related to increases in tolerance to diseases, as reported by Mushayi et al. (2020) and Kulka et al. (2018).

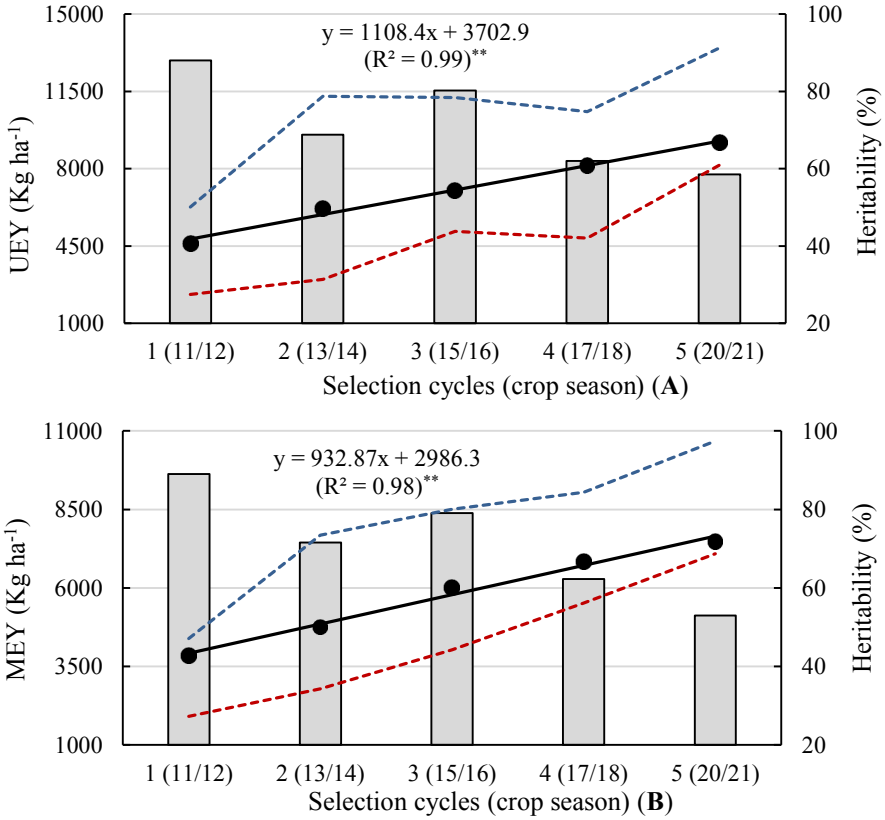

Figure 3. Mean (●), heritability (■), upper limit (---), and lower limit (---) of unhusked ear yield (UEY) and marketable ear yield (MEY) over five selection cycles (2011-2012, 2013-2014, 2015-2016, 2017-2018, and 2020-20/21) of evaluation of 64 progenies of corn half-sib progenies focused on fresh corn production.

There was a mean increase, in each selection cycle, of approximately 1.87 for Falker relative chlorophyll index, 6.5 cm for plant height, 4.4 cm for first ear insertion height, 0.7 cm for ear diameter, 0.8 cm for ear length, 1,108 kg ha^{-1} for unhusked ear yield, and 933 kg ha^{-1} for marketable ear yield (Figures 1, 2 and 3). The ear quality was confirmed by the yield of marketable ears, which were more uniform and with an adequate size to be marketed in trays, with possibility of gains even after five cycles, despite the reduction in h^2. The results obtained with the five selection cycles for these variables were 55.14 falker, 208.84 cm, 104.26 cm, 7.85 cm, 19.92 cm, 9,245 kg ha^{-1}, and 7,651 kg ha^{-1}, respectively, which denoted the possibility of continuing the breeding program focused on varieties that can occupy this consumer market.

Costa et al. (2021) evaluated the genetic variability and potential of 167 half-sib progenies of corn with intrapopulation recurrent selection and found heritability values of approximately 23%, 36%, 26%, 46%, 49%, and 46% for plant height, ear height, ear diameter, ear length, yield of ears with husks, and commercial ears, respectively. The results showed lower possibility of yield gains in the first cycle, with similar mean yields (4,580 and 4,864 kg ha^{-1}) for ears with and without husks at the initial phase of the program. However, the results were seen as promising and can generate new populations for the market and improve new researches, as found in the present work.

CONCLUSIONS

The half-sib progenies of fresh corn exhibited genetic variability through intrapopulation recurrent selection in the different selection cycles, which is still promising for further selections after five cycles, with evaluation of 64 progenies per cycle. The base population from crossings between hybrids for tropical and temperate climates showed to be promising for increasing the genetic base of fresh corn

populations, with satisfactory gains over the five cycles for the different variables evaluated, presenting mean heritability between the cycles of approximately 78.9% for relative chlorophyll index, 62.2% for plant height, 75.1% for ear insertion height, 70% for ear diameter, 56.6% for ear length, 71.4% for unhusked ear yield, and 71% for marketable ear yield.

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