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Selection of S3 progenies of super sweet corn based on agronomic performance of topcrosses

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ABSTRACT

The aim of this study was to select S3 progenies of super sweet corn based on agronomic performance, evaluated in topcrosses with the narrow genetic base tester Honey Sweeter (Seminis®). The experiment was carried out in Guarapuava-PR. We evaluated 22 topcross hybrids and three checks, in two sowing times, in randomized blocks design with three replications. Six traits were evaluated: total yield of husked ears, commercial yield of husked ears, grain yield, grain length, ear diameter and total soluble solids content. Considering the set of evaluated traits, the topcrosses with progenies D2-07, D3-28, D4-53 and D5-24 were superior to the others; therefore, these progenies should continue in the inbreeding process and be evaluated in crosses with elite inbred lines with potential to generate competitive super sweet corn single hybrids.

Keywords: *Zea mays* var. *saccharata*, sweet corn breeding, shrunken 2 (*sh2*).

RESUMO

Seleção de progênies S3 de milho super doce com base no desempenho agronômico de topcrosses

O trabalho teve por objetivo selecionar progênies S3 de milho super doce com base no desempenho agronômico, avaliadas em *topcrosses* com o testador Honey Sweeter, de base genética estreita. O experimento foi conduzido em Guarapuava-PR. Foram avaliados 22 híbridos *topcrosses* e três testemunhas, em duas épocas de semeadura, no delineamento em blocos ao acaso, com três repetições. Foram avaliadas seis características: produtividade total de espigas sem palha, produtividade comercial de espigas sem palha, produtividade de grãos, comprimento de grãos, diâmetro de espiga e teor de sólidos solúveis totais. Considerando o conjunto das características avaliadas, os *topcrosses* com as progênies D2-07, D3-28, D4-53 e D5-24 foram superiores aos demais; portanto, essas progênies devem seguir no processo de endogamia e ser avaliadas em cruzamentos com linhagens elites com potencial para geração de híbridos simples de milho super doce competitivos.

Palavras-chave: *Zea mays* var. *saccharata*, melhoramento do milho super doce, shrunken 2 (*sh2*).

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The super sweet corn (*Zea mays* var. *saccharata*) is a special kind of corn with high market value added. The super sweet corn is a vegetable available canned, frozen, *in natura*, dehydrated or even as baby-corn, when the ears are harvested before pollination (Reis *et al.*, 2011).

The super sweet corn is different from the common maize due to the recessive homozygous genes which prevent the conversion of sugars to starch in the endosperm, resulting in high concentration of reducing sugars (Zucharelli *et al.*, 2012). The genes responsible for the super sweet characteristic are brittle 1 (*bt1*), brittle 2 (*bt2*), shrunken 2 (*sh2*) and sugary enhancer (*se*), whereas the sweet corn is due to the genes amylose extender (*ae*), dull (*du*) and sugary (*su*) (Tracy, 2001).

Most of the super sweet corn hybrids available in Brazil have the shrunken-2 gene, which promotes a higher concentration of sucrose in the endosperm when compared to genotypes carrying other genes (Gonçalves *et al.*, 2018). As Brazil is a great producer of common corn, the country has also potential to become a great producer of sweet corn. However, the sweet corn is relatively little exploited, due to its limited consumption and few hybrids available in the market, adapted to the several climatic conditions of Brazilian territory (Teixeira *et al.*, 2013).

As the sweet corn market for canning and frozen industry has expanded, the breeders face a challenge to develop genotypes showing high yield and also high quality (Ufaz & Galili, 2008). Besides, the genotypes with potential for green corn must prolong harvest longevity, present ears larger than 15 cm (Albuquerque *et al.*, 2008), and also cream/yellow colored grains (Guimarães, 2014).

Evaluating the combining ability of progenies is important in breeding programs in order to evaluate the relative merit of partially inbreds in topcrosses with a common tester of narrow or broad genetic base, whose evaluation is made in experiments with replications. Thus, the progenies with inferior agronomic performance can be eliminated, making the program for hybrid development more rational and efficient (Cancellier *et al.*, 2011; Paterniani *et al.*, 2011).

Considering the need to develop super sweet corn breeding program, this study aimed to select S3 progenies of super sweet corn based on the agronomic performance evaluated in topcrosses with a narrow genetic base tester.

MATERIAL AND METHODS

The super sweet corn topcross hybrids were obtained from the crossings of 22 S3 progenies carrying the shrunken-2 (*sh2*) gene with the commercial hybrid Honey Sweeter, used as tester, and three checks (Variety BR400, hybrid Super doce TecnoSeed and Honey Sweeter). The hybrid Honey Sweeter (*sh2sh2*) is adapted in the country by Seminis®. It has soft grains and sweet flavor, ears suitable for the fresh market and the processing industry; it is also tolerant to the main diseases and pests of the crop. The super sweet variety BR400, which carries the *bt2* gene was developed by Embrapa using the germplasm introduced from Hawaí (EUA), series "Super Sweet 9" (Souza *et al.*, 2021).

The experiments were carried out in the field in Guarapuava-PR, Brazil, in two different sowing times: November 15 and December 6, 2014. During the experiments, a uniform rainfall distribution was noticed at the second sowing time, temperature raised from the second half of January (Shioga *et al.*, 2015). The experimental design was randomized blocks with three replications at both sowing times. Each useful plot consisted of two 5.0-m long rows, spacing 0.8 m between rows, with population of 62,500 plants ha^{-1}.

The sowing fertilization was performed using 400 kg ha^{-1} of formulation N-P-K (10-30-20). Top dressing fertilization was performed using 400 kg ha^{-1} urea 46-00-00, splitted in two applications in vegetative stages V2-V3 (second and third leaf) and V5-V6 (fifth and sixth leaf).

Pests, pathogens and weeds were controlled according to the necessity and technical recommendation for the crop. The ears were harvested when the grains reached the milky stage, 73-78% water content, approximately 126 days after sowing.

Six traits were evaluated: 1) total yield of husked ears (YHE, t ha^{-1}); 2) commercial yield of husked ears (YCE, t ha^{-1}), larger than 15 cm and 4 cm in diameter; 3) grain yield (GY, t ha^{-1}), weight of the grains of all ears after threshing; 4) grain length (GL, mm), measured with a digital caliper; 5) ear diameter (ED, mm), measured with a digital caliper (five ears randomly sampled); and 6) total soluble solids content (SS, °Brix), obtained using a digital refractometer.

For the evaluated traits, Lilliefors test was applied and after verifying the normality of data ($p<0.05$), we performed the analysis of variance (ANAVA). When the source of variation was significant, averages were grouped using Scott & Knott test at 5% probability, using Genes software (Cruz, 2016).

RESULTS AND DISCUSSION

The experiment showed an appropriate experimental accuracy for the evaluated traits, as verified in other experiments with super sweet corn (Santos *et al.*, 2014; Xavier *et al.*, 2019).

Significant differences among the topcross hybrids were noticed for all evaluated traits, showing the genetic variability of the respective progenies to be selected. There was significant difference among the averages of topcross hybrids and the checks for all evaluated traits.

The effects of sowing time and the genotypes x sowing times interaction were not significant only for the solid soluble content (SS), whose genotypic determination coefficient of 99.54% indicates high heritability and little influence by the environment, while genotypes x sowing times interaction was significant for the other evaluated traits. Gava *et al.* (2021) also reported genotypes x sowing seasons interaction for yield of husked ears (YHE) and grain yield (GY), in the evaluation of experimental super sweet corn hybrids in Guarapuava-PR.

The general averages of YHE, yield of commercial husked ears (YCE) and GY in the second sowing time were superior when compared with the first sowing time (Table 1), as well as, for these same traits, the averages of topcross hybrids were superior when compared with the averages of checks, in both sowing times. The highest potential for yield improvement is determined by the interactions of correspondent genes which were inherited from parents and depend on environmental conditions (Iriany *et al.*, 2011).

For soluble solids content, the means of the topcross hybrids were allocated in the same group of the checks Honey Sweeter and BR400 (Table 2), proving the possibility of selecting progenies based on topcross performance, which have the potential to generate competitive hybrids in the market.

Total yield of husked ears (YHE) of topcross hybrids with progenies D2-07, D3-28, D4-53 and D5-24 stood out in both sowing times, being in the group of the best means (Table 1). This trait has direct effect on the grain yield of the super sweet corn, being a more practical measure which may reflect interest for industrial processing (Ilker, 2011).

In relation to YCE, whose genotypes x sowing times interaction was significant, the means ranged from 12.97 t ha^{-1} to 16.33 t ha^{-1}, however the topcross hybrids with progenies D2-07, D3-28 and D4-53 were grouped in the set of superior means in both sowing times (Table 1). These means of YCE were superior to the ones reported by Souza *et al.* (2013) in the evaluation of sweet corn hybrids in different plant populations, where the hybrid RB-6324 reached 7.18 t ha^{-1} in density of 70,000 plants ha^{-1}.

For grain yield (GY), in the first sowing time, the topcross hybrids with the progenies D2-07, D3-28, D4-8, D4-53 and D5-24 stood out, ranging from 9.80 t ha^{-1} to 12.45 t ha^{-1}, and the

Table 1. Means of total yield of husked ears (YHE), commercial yield of husked ears (YCE) and grain yield (GY) of 22 super sweet corn topcross hybrids and three commercial hybrids (checks), evaluated in two sowing times in 2014/15 crop season in Guarapuava-PR, Brazil. Guarapuava, UNICENTRO, 2014-2015.

Genotypes	YHE (t ha^{-1})		YCE (t ha^{-1})		GY (t ha^{-1})	
	1st sowing time	2nd sowing time	1st sowing time	2nd sowing time	1st sowing time	2nd sowing time
D2-07 x HS	17.29 a	17.70 a	14.37 a A	16.33 a A	11.16 a	10.48 a
D2-15 x HS	13.18 b	15.98 b	8.87 b A	12.00 b A	8.20 b	9.54 a
D2-41 x HS	13.14 b	17.09 a	9.99 b B	14.64 a A	8.42 b	11.00 a
D2-58 x HS	13.96 b	16.82 a	10.63 b B	15.08 a A	9.03 b	10.40 a
D3-28 x HS	18.71 a	18.40 a	14.81 a A	16.03 a A	12.45 a	12.15 a
D3-39 x HS	13.75 b	18.04 a	10.30 b B	14.64 a A	8.02 b	11.97 a
D4-01 x HS	13.06 b	15.93 b	9.00 b B	13.55 a A	8.91 b	10.18 a
D4-08 x HS	15.18 a	15.18 b	10.32 b A	11.11 b A	10.16 a	10.21 a
D4-16 x HS	12.28 b	17.49 a	8.01 c B	14.76 a A	8.07 b	10.81 a
D4-20 x HS	12.03 b	15.06 b	7.56 c B	11.66 b A	7.76 b	10.02 a
D4-29 x HS	9.82 c	12.58 c	7.15 c A	9.25 c A	5.83 c	8.54 b
D4-31 x HS	14.05 b	17.98 a	10.80 b B	15.82 a A	9.03 b	12.18 a
D4-39 x HS	12.82 b	15.61 b	9.97 b A	12.36 b A	8.57 b	9.66 a
D4-53 x HS	16.46 a	18.60 a	12.97 a B	16.29 a A	1.08 a	11.97 a
D4-54 x HS	13.64 b	14.68 b	10.02 b A	12.87 a A	8.59 b	10.67 a
D5-11 x HS	13.59 b	16.68 a	8.77 b B	14.12 a A	8.31 b	11.49 a
D5-14 x HS	12.57 b	17.25 a	7.47 c B	14.23 a A	7.67 b	11.13 a
D5-24 x HS	15.78 a	18.30 a	10.97 b B	16.52 a A	9.80 a	11.50 a
D5-46 x HS	13.96 b	16.02 b	9.80 b A	12.11 b A	8.41 b	10.14 a
D5-51 x HS	13.88 b	18.77 a	9.57 b B	15.93 a A	9.36 b	12.69 a
D5-55 x HS	11.14 c	15.23 b	6.70 c B	13.17 a A	7.22 b	10.00 a
D5-57 x HS	13.77 b	15.89 b	10.45 b A	12.92 a A	8.62 b	10.75 a
Honey Sweeter	8.56 c	15.00 b	3.96 d B	13.86 a A	5.10 c	10.25 a
BR400	8.90 c	9.52 c	4.40 d B	7.67 c A	2.77 d	5.52 c
Super doce TecnoSeed	6.95 c	11.33 c	2.65 d B	8.82 c A	3.62 d	6.63 c
Average of genotypes	13.14 B	16.04 A	9.18 B	13.43 A	8.23 B	10.40 A
Average of TCH	13.82 a A	16.60 a A	9.93 a A	13.88 a A	8.84 a A	10.79 a A
Average of checks	8.14 b	11.95 b	3.67 b B	10.12 b A	3.83 b B	7.47 b
CV (%)	13.79	12.57	19.08	16.35	16.35	13.46

Means followed by the same letter, uppercase in lines and lowercase in columns, belong to the same group, by Scott & Knott grouping test at 5% probability. HS= Honey Sweeter. TCH= Topcross hybrids; 1st sowing = on November 15, 2014; 2nd sowing = on December 6, 2014.

checks were classified in the groups with inferior means (Table 1). However, in the second sowing time only the topcross hybrid with the progeny D4-29 and the checks Super doce TecnoSeed and BR400 were not classified in the group with higher means. These results were superior to the ones found by Luz *et al.* (2014) evaluating simple experimental hybrids of sweet corn, showing means of grain yield ranging from 4.76 to 11.70 t ha^{-1} in different harvesting intervals.

The SS means of topcross hybrids did not differ from the means of the checks BR400 and Honey Sweeter, which meet the market demand for canned product. Thus, we conclude that the progenies have potential to generate new hybrids with appropriate soluble solids contents. The identification of genotypes with high soluble solids contents and high grain yield is desirable in genetic breeding of sweet corn (Suzukawa *et al.*, 2018).

The grain length (GL) and ear diameter (ED) general averages of genotypes was superior in the first sowing time. The topcross hybrids had the best average for GL, being considered superior to the commercial checks in both sowing times (Table 2).

Twelve topcross hybrids were included in the group with higher means of ED in the first sowing time, and in the second sowing time only four topcross hybrids remained in the group of the best means (Table 2). The topcross hybrids with progenies D3-39, D4-20 and D4-31

Table 2. Means of total soluble solids content (SS), ear diameter (ED) and grain length (GL) of 22 super sweet corn topcross hybrids and three commercial hybrids (checks) evaluated in two sowing times in 2014/15 crop season in Guarapuava-PR, Brazil. Guarapuava, UNICENTRO, 2014-2015.

Genotypes	SS* (°Brix)	ED (mm)		GL (mm)	
	Average of sowings	1st Sowing time	2nd Sowing time	1st Sowing time	2nd Sowing time
D2-07 x HS	13.9 b	54.0 a A	50.8b B	13.39a A	12.01b B
D2-15 x HS	13.8 b	49.0 b A	50.3b A	12.80b A	11.86b B
D2-41 x HS	13.4 b	50.9 b A	50.4b A	12.53b A	12.47a A
D2-58 x HS	13.9 b	51.9 a A	50.7b A	13.72a A	11.78b B
D3-28 x HS	13.8 b	53.9 a A	49.5b B	13.74a A	11.98b B
D3-39 x HS	14.1 b	53.3 a A	54.4a A	13.24a A	12.09b B
D4-01 x HS	14.7 b	45.7 c A	47.3c A	12.78b A	11.67b B
D4-08 x HS	13.2 b	50.3 b A	45.7c B	13.16a A	11.83b B
D4-16 x HS	15.2 b	48.9 b A	46.7c A	12.35b A	11.03b B
D4-20 x HS	15.2 b	52.3 a A	52.9a A	13.41a A	11.93b B
D4-29 x HS	14.9 b	49.4 b A	50.2b A	12.79b A	12.21a A
D4-31 x HS	14.0 b	52.1 a A	52.2a A	12.77b A	12.42a A
D4-39 x HS	14.1 b	50.2 b A	48.3c A	13.14a A	11.04b B
D4-53 x HS	13.7 b	52.4 a A	48.0c B	13.88a A	12.29a B
D4-54 x HS	14.6 b	52.1 a A	49.2b A	13.73a A	11.91b B
D5-11 x HS	14.5 b	49.6 b A	52.3a A	12.20b A	12.28a A
D5-14 x HS	12.3 b	51.7 a A	48.3c B	12.76b A	11.58b B
D5-24 x HS	12.8 b	52.8 a A	50.5b A	13.45a A	12.41a B
D5-46 x HS	13.5 b	53.7 a A	50.7b A	13.27a A	11.65b B
D5-51 x HS	14.1 b	51.8 a A	51.2b A	13.49a A	11.97b B
D5-55 x HS	13.8 b	51.1 b A	49.0b A	13.62a A	12.48a B
D5-57 x HS	12.2 b	49.9 b A	51.0b A	13.02b A	11.89b B
Honey Sweeter	13.5 b	53.6 a A	53.9a A	13.88a A	13.22a A
BR400	12.3 b	43.3 c A	41.3d A	10.71c A	9.09c B
Superdoce TecnoSeed	23.6 a	43.5 c A	44.1d A	10.67c A	9.88c A
Average of genotypes	14.6	50.71 A	49.55 B	12.98 A	11.80 B
Average of TCH	13.9 b	51.24 a A	49.98a A	13.15a A	11.94a B
Average of checks	16.4 a	46.82 b A	46.43b A	11.76b A	10.73b B
CV (%)	7.66	4.16	3.32	3.29	5.26

Means followed by the same letter, uppercase in lines and lowercase in columns, belong to the same group, by Scott & Knott grouping test at 5% probability. HS= Honey Sweeter. *SS contents represent the averages of sowing times; TCH= Topcross hybrids; 1st sowing = on November 15, 2014; 2nd sowing = on December 6, 2014.

and the check Honey Sweeter remained in the group of superior means for ED in both sowing times, with means between 52.1 and 53.3 mm, superior to the ones obtained by Xavier *et al.* (2019), who obtained values up to 51 mm evaluating the potential of diallel hybrids of super sweet corn S4 lines.

Grain length is an important attribute for the sweet corn crop, considering the industrial processing, since it determines the grain size after threshing (Solomon *et al.*, 2012). In the first sowing time, 14 genotypes were classified in the group of higher GL means. Only the topcross hybrids with progenies D4-53, D5-24 and D5-55 and the check Honey Sweeter showed higher means for GL in both sowing times (Table 2).

The topcross hybrids with progenies D2-07, D3-28, D4-53 and D5-24 stood out for the evaluated traits, therefore, these progenies should continue in inbreeding process and evaluated in crossings with elite inbred lines showing potential for generating competitive single hybrids.

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