BRS Deni – Super-sweet corn open-pollinated variety

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Abstract: *BRS Deni is a super-sweet corn open-pollinated variety, developed and released by the Brazilian Agricultural Research Corporation (Embrapa) that combines high yield and good ear and grain quality and lower production costs. The grain can be consumed fresh or canned.*

Keywords: *Zea mays, Shrunken-2, specialty corn*

INTRODUCTION

Maize (*Zea mays L.*) is a food crop with numerous forms of use. For some of them, specific properties are required that can be found in cultivars classified as special. Sweet and super-sweet corn for example are considered special, due to variations in one or more alleles that modify the sugar concentration, resulting in changes in taste and flavor of the grains. The plant and ear properties and seed viability and texture of these special types of corn are also differentiated.

The sweeter flavor of the grains can be explained by the higher sugar-to-starch ratio in the endosperm than in other corn types. The grain sugar content of field corn is only 3%, that of sweet corn from 9% to 14%, while grains of the so-called super-sweet cultivars contain between 15% and 25%. These variations are genetically controlled, and the alleles that define the sweet and super-sweet phenotypes are generally recessive (Tracy 2001). Some alleles that are associated with the super-sweet corn cultivars of most widespread commercial use are shrunken-2 (*sh2*) (Yousef and Juvik 2002) and brittle-2 (*bt2*) genes (Brewbaker and Banafunzi 1975, Brewbaker 1977).

Other aspects that differentiate sweet and super-sweet from field corn are harvest maturity, cultivation practices and forms of marketing. The ears of the so-called specialty corn are harvested in the green stage, with approximately 75% moisture. For cultivation, which is labor-intensive, irrigation-dependent and requires high technology investment, small areas are often used. Sweet corn is a perishable product for human consumption with high value. Thus, sweet and super-sweet corn are classified as horticultural crops.

In the United States of America, sweet corn in fresh or processed form is one of the most widely consumed vegetables (Confederação da Agricultura e Pecuária do Brasil 2017). In Brazil however, fresh consumption is very restricted, since sweet corn is almost exclusively used for canning in the food industry, regardless of the potential for consumption as fresh green maize (Guia Veja 2013).

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Between 2001 and 2009, the cultivated area and amount of sweet corn seed sold in Brazil remained stable, whereas production increased, possibly due to the higher yields of genetically improved cultivars (Miranda 2016). From 2009 to 2012, the value of the annual production of sweet corn rose from R$ 11 to 14.5 million, indicating a relative growth of around 30% in three years (Associação Brasileira do Comércio de Sementes e Mudas 2014). In 2012, in terms of volume, sweet corn was the sixth most sold vegetable in Brazil. The production cost of sweet corn was estimated at R$ 132.0 million and generated a gross return of around R$ 170.4 million, i.e., approximately 1.3 of the production costs. In 2012, the mean seed cost represented around 10.5% of the production costs and sweet corn ranked ninth among the vegetables with highest seed sales value (Associação Brasileira do Comércio de Sementes e Mudas 2014). In addition, the agro-industrial chain for sweet corn is larger than that of field corn, due to the industrial processing (canning), which adds value to the product after harvesting (Miranda 2016).

Breeding of sweet corn in Brazil was initiated at Embrapa Maize and Sorghum in the 1970s, with the introduction of basic genotypes from universities in the USA. This exotic germplasm was crossed with dent lines from field corn breeding programs in a joint program between Embrapa Maize and Sorghum and Embrapa Vegetables, and resulted in the development of the varieties BR 400 (Superdoce), BR 401 (Doce-de-ouro), BR 402 (Doce cristal), BR 420 (Docemel) and BR 421 (Lili). In the 1990s, the development of new sweet corn lines was initiated at Embrapa Maize and Sorghum, with the introgression of bt-2 and sh-2 alleles into elite lines with normal endosperm. Currently, consumers prefer cultivars classified as super-sweet with excellent quality properties, e.g., pericarp softness and flavor; desirable appearance and ear size and uniform maturation (Teixeira et al. 2013). In view of this market demand, the single-cross hybrid BRS Vivi was developed by Embrapa Maize and Sorghum (Teixeira et al. 2014) and registered by the Brazilian Ministry of Agriculture, Livestock and Supply (MAPA), in May 2010, (Brasil 2021). Since then, the sweet maize breeding program of Embrapa Maize and Sorghum has been working to develop an open-pollinated variety, BRS Deni.

In the 11 years between the release of these two cultivars, the market offer of sweet corn cultivars shifted. The Ministry of Agriculture, Livestock and Food Supply came to register sweet corn cultivars in separate cultivation groups, apart from those of field corn. Currently, there are two groups for this specialty corn, identified as: *Zea mays* var *saccharina*, which covers registries of the late 1990s, when cultivars were classified as sweet corn, with 113 cultivars at the time of registration of variety BRS Deni; and the new group *Zea mays* L. *saccharata* Koem, of super-sweet cultivars (shrunken-2 genotype). Cultivars UENF SD 08 and UENF SD 09 were the first to be recorded in this group (Pereira et al. 2019). It should be mentioned that the group *Zea mays* var *saccharina* contains cultivars classified as sweet and super-sweet, although the more recent group is being used exclusively for super-sweet cultivars. In May 2021, these two groups of sweet corn comprised 116 registered lines. Some of them were classified as parent lines and only 67 (58%) were registered as cultivars. An analysis of the offer dynamics of these 67 cultivars for the period between the registries of cultivars BRS Vivi and BRS Deni shows that 40 new cultivars were released in that interval, which is equivalent to about 60% of the total available cultivars. The rapid growth in the offer of cultivars suggests an intensification of the sweet corn seed market, which possibly contributes to increases in yield and product quality and could boost the growth of the sector. In addition to the beneficial effects on the sweet corn production chain, the increase in the offer of cultivars favors the expansion of the genetic base of sweet corn. The registration by MAPA does not indicate the type of cultivars, however, possibly most of them are hybrids.

Open-pollinated varieties can be more advantageous than hybrids, due to the lower costs of seed multiplication. This is relevant in sweet corn because the seed production cost can be higher than that of field corn seeds, due to the low yield of sweet corn inbred lines. On the other hand, plants of open-pollinated varieties may be somewhat non-homogeneous, which is undesirable. In view of the lack of open-pollinated super-sweet corn cultivars, variety BRS Deni was developed by Embrapa to expand the options. The open-pollinated cultivar BRS Deni can stimulate sweet corn production by small farmers and in family agriculture, which may popularize green corn consumption. Thus, a new consumption habit may be created. The sale of fresh sweet corn ears on local markets could become an extra income source in small communities. The objective of this study was to describe the variety BRS Deni and its characteristics.

BREEDING METHODS

The variety BRS Deni was developed from a synthetic population derived from two types of parents: super-sweet lines of the Embrapa Maize and Sorghum breeding program and commercial hybrids, including BRS Vivi. Seeds from

this population were harvested and sown over three generations for recombination and selection for yield, quality and agronomic traits. The last selection was carried out in Sete Lagoas, Minas Gerais, Brazil, in 2014.

With the recombined generations, the variety was tested in trials to evaluate yield, quality and agronomics traits, using the hybrids BRS Vivi, Tropical Plus and SWB 551 as checks. The evaluation trials were conducted in: Sete Lagoas/2015 (L1), Londrina/2015 (L2), Sete Lagoas/2016 (L3), Janaúba/2016 (L4), Londrina/2017 (L5), and Passo Fundo/2017 (L6) in a randomized block design with three replications and experimental plots with four 5-m rows, spaced 80 cm apart. In these trials, the following traits were evaluated: number of days to female flowering (FF), from seedling germination until 50% of the plants in the plot emit style-stigmas; plant height (PH, cm) and first ear height (EH, cm); prolificity (PR), based on the ratio of number of ears to number of plants per plot; grain yield at maturity (GY, t ha^{-1}); unhusked ear yield of green corn (EY, tons/ha); ear length (LE, cm) and diameter (DE, mm) of unhusked ears at the green corn stage; number of grain rows per ear (NR); mean ear weight (EW, g); grain weight per ear (GW, g) at the green corn stage; and brix degrees (BR) computed as the mean of two samples of ground grains measured with a portable digital refractometer (Atago PALM-1). Analysis of variance and the Tukey mean test were performed using software GENES (Cruz 2006).

Variety BRS Deni was characterized based on the methodology for distinguishability, homogeneity, and stability (DHS) indicated for field corn (Brasil 2020), in Sete Lagoas, in 2015 and 2016. The variety was evaluated on a 1 to 5 scale in

Table 1. Summary of analysis of variance and agronomic trait means of the cultivar evaluation trials of sweet corn in Sete Lagoas/2015 (L1), Londrina/2015 (L2), Sete Lagoas/2016 (L3), Janaúba/2016 (L4), Londrina/2017 (L5) and Passo Fundo/2017 (L6)

SV	FF[1,2] df	MS	F	PH (cm)[3] df	MS	F	EH (cm)[3] MS	F
Block/Location	6	0.56		10	223.22		159.82	
Treatment (T)	3	2.99	6.87 *	3	508.47	3.47	517.75	3.79 *
Location (L)	2	2.58	4.65	4	22614.96	101.31 **	3541.02	22.16 **
T x L	6	0.44	0.53	12	146.42	2.19 *	136.58	1.80
Error	18	0.81		30	66.75		75.95	
Mean		59.92			261.50		132.32	
CV (%)		1.50			3.12		6.59	
Means[7]								
BRS Vivi		60.44	a		267.13		137.37	a
Tropical Plus		59.22	b		254.87		123.83	b
SWB 551		60.33	ab		265.60		134.20	a
BRS Deni		59.67	ab		258.23		133.57	a

SV	PR[4] df	MS	F	GY[5] df	MS	F	EY[6] df	MS	F
Block/Location	8	0.0134		12	0.37		4	1.22	
Treatment (T)	3	0.0984	1.53	3	0.88	1.24	3	3.26	0.64
Location (L)	3	0.0678	5.07 **	5	21.39	57.36 **	1	37.25	30.30
T x L	9	0.0619	2.57 **	15	0.71	1.74	3	5.08	4.88 *
Error	24	0.0240		36	0.41		12	1.04	
Mean		1.0235			3.32			10.35	
CV (%)		15.14			19.22			9.86	
Means									
BRS Vivi		0.9150			3.50			10.40	
Tropical Plus		0.9980			3.08			9.53	
SWB 551		1.1245			3.50			11.31	
BRS Deni		1.0564			3.18			10.17	

[1] FF: number of days to female flowering, PH: plant height, EH: first ear height, PR: prolificity, GY: grain yield at maturity, EY: unhusked ear yield at green corn stage [2] Trial in environments 1, 3 and 4; [3] Trial in environments 1 to 5; [4] Trial in environments 1, 2, 4 and 5; [5] Trial in environments 1 to 6; [6] Trial in environments 1 and 3; [7] Means followed by the same letter did not differ by the Tukey test at 5% probability. ** and * F test significant at 1 and 5% probability, respectively.

Table 2. Summary of analysis of variances and means for ear and grain quality traits in sweet corn trials in Sete Lagoas/2015 (L1) and 2016/(L3)

SV	df	LE (cm)[1] MS	F	DE (mm) MS	F	NR MS	F
Block/Location	4	0.32		1.00		0.33	
Treatment (T)	3	1.96	2.44	104.20	10.30 *	0.40	4.76
Location (L)	1	6.00	16.57 **	9.75	9.73 *	0.03	0.08
T x L	3	0.80	2.43	10.11	2.84	0.08	0.34
Error	12	0.33		3.57		0.25	
Mean		16.48		40.00		14.98	
CV (%)		3.49		4.72		3.31	
Means[2]							
BRS Vivi		17.00		46.03 a		15.10	
Tropical Plus		16.74		39.51 b		15.26	
SWB 551		15.70		36.89 b		14.90	
BRS Deni		16.51		37.60 b		14.67	

SV	df	EW (g) MS	F	GW (g) MS	F	BR MS	F
Block/Location	4	58.49		149.99		0.57	
Treatment (T)	3	5471.24	6.68	44.16	0.16	6.82	4.60
Location (L)	1	618.13	10.57 *	54.30	0.36	0.33	0.57
T x L	3	818.81	4.80 *	259.86	2.70	1.48	0.98
Error	12	170.57		96.24		0.81	
Mean		158.77		104.19		15.64	
CV (%)		8.22		9.41		7.84	
Means							
BRS Vivi		201.46		100.37		16.13	
Tropical Plus		158.66		106.76		16.84	
SWB 551		135.70		105.04		14.47	
BRS Deni		139.25		104.62		15.04	

[1] LE: length of unhusked ears at green corn stage, DE: diameter of unhusked ears at green corn stage, NR: number of grain rows per ear, EW: mean ear weight at green corn stage, GW: mean grain weight per ear at green corn stage, BR: brix degrees; [2] Means followed by the same letter did not differ by the Tukey test at 5% probability. ** and * Significant F test at 1 and 5% probability, respectively.

Sete Lagoas, in 2019, for reaction to white spot, corn stunt, common rust and leaf anthracnose, as follows: 1 - highly resistant, 2 - resistant, 3 - moderately resistant, 4 - susceptible and 5 - highly susceptible.

PERFORMANCE

Analyses of variance and means of yield and agronomic traits of sweet corn cultivars are shown in Table 1 and ear and grain quality traits in Table 2. It is noteworthy that the percentage variation coefficient (CV%) in the analysis of variance of grain yield at maturity was below 20%, according to the recommended threshold (Brasil 2017) for inclusion in tests of cultivation and use for field corn.

Sweet corn is harvested and sold at the green corn stage; in other words, the production of green corn ears corresponds to the yield. The comparison of means showed that the mean grain yield at the end of the cycle was only 3.35 t ha^{-1}, as expected for sweet corn, although this estimate is far below the average field corn yield in Brazil, which exceeds 5 t ha^{-1} (IBGE 2021). The estimated mean ear yield of green corn on the other hand was 10.35 t ha^{-1} and was associated with a CV (%) of 9.86, indicating good experimental precision.

With regard to the evaluated traits, the treatments differed only for number of days to female flowering, ear height and ear diameter. This indicates that the performance of the open-pollinated variety BRS Deni was similar to that of other cultivars in terms of plant height, prolificity, grain yield at maturity, green corn ear yield, ear length, number of grain rows per ear, ear weight, grain weight per ear and brix degrees. These results suggest that BRS Deni can reach

very high levels of yield and quality for most relevant characters of sweet corn, especially green corn ear yield and ear weight, similar to the commercial hybrids used as controls. It is worth mentioning that the mean of brix degrees in the trial exceeded 15, which classifies the cultivars under study as super-sweet (Tracy 2001).

Significant differences between cultivars were found for some traits, e.g., the hybrid Tropical Plus takes fewer days to female flowering, is earlier and has a shorter plant height. In terms of ear diameter, the performance of BRS Deni was similar to that of Tropical Plus and SWB 551, which are suitable for the canning industry.

A location effect on plant and ear height, prolificity, grain yield at maturity, ear length and diameter and mean ear weight was detected, which indicates that the location effect must be evaluated to obtain favorable results in sweet corn yield and quality. There was a low interaction between traits and locations for some traits, including ear yield and mean ear weight, which directly affect yield. Thus, cv. BRS Deni should be evaluated under different environmental conditions to generate data about the yield potential. According to the results at the evaluation locations, cultivar BRS Deni is recommended for cultivation in the states of Goiás, Minas Gerais, Paraná and Rio Grande do Sul and in the Federal District.

OTHER TRAITS

Characteristics of the variety BRS Deni assessed in the DHS evaluations and related to product quality and pathogen reaction are presented in Table 3. The stem diameter, degree-days to male flowering and length and number of tassel branches of variety BRS Deni were classified as intermediate. The ears have oblique insertion, a conical-cylindrical shape, good husk cover, on average 11 husk layers per ear, straight grain rows, white cobs and a cob-to-ear diameter ratio of 0.605. The grains are light yellow with colorless pericarp and grain depth of 1.0 cm. The 1000-grain and hectoliter weight were estimated at 142.3 g and 61 kg, respectively. As expected, these weight-to-volume ratios were low for sweet corn seeds, due to the wrinkled grain texture at maturity. Thus, the ear- and grain-related properties indicate that the quality of the variety is suited for fresh consumption as well as for the canning industry.

Table 3. Means of traits related to ears, grains and pathogen reactions of the super-sweet corn variety BRS Deni

Characteristics*	Means
Stem diameter	23.45 mm
Tassel stem length	46.7 cm
Number of degree days from sowing to 50% pollen shed	951.5
Number of secondary branches on tassel	15.75
Ear slope	Oblique
Ear weight with husk at green grain stage	225 g
Husking degree	high (ear completely covered)
Number of husk layers	11 layers
Ear shape	Conical/Cylindrical
Grain row direction from ear base to apex	Straight
Ratio ear to cob diameter	0.605
Cob color	White
Percentage of ear weight corresponding to grains (at 13% moisture)	80.21%
Stigma-style color	Absent
Grain color	Light yellow
Pericarp color	Absent
Grain depth	1.0 cm
1000-grain weight (adjusted to 13% moisture)	142.30 g
Hectoliter grain weight	0.61 kg
Reaction to white spot **	4: susceptible
Reaction to maize stunt **	3: moderately resistant
Reaction to common rust **	2: resistant
Reaction to leaf anthracnose **	2: resistant

* Planting occurred in spatial and/or temporal isolation from other maize crops to avoid pollen contamination. Mean stand 50,000 plants/ha; rows spaced 80cm and plants 20 cm apart. ** Pathogen reaction scale from 1 to 5, where: 1 - highly resistant, 2 - resistant, 3 - moderately resistant, 4 - susceptible and 5 - highly susceptible.

In the pathogen reaction evaluations under the conditions of Sete Lagoas, in 2019, variety BRS Deni was classified as susceptible to white spot, moderately resistant to corn stunt and resistant to common rust and leaf anthracnose.

SEED PRODUCTION

Cultivar BRS Deni was protected and registered, respectively, by the Ministry of Agriculture, Livestock and Food Supply (MAPA) on September 24, 2019 (N. 20200059) and on May 25, 2021 (N. 45998). The Secretariat of Innovation and Business of the Brazilian Agricultural Research Corporation (Embrapa-SIN) is responsible for basic seed production.

CONCLUSION

The open-pollinated variety BRS Deni had a similar performance as the cultivars BRS Vivi, Tropical Plus and SWB 551 for plant height, prolificity, grain yield at maturity, ear yield at the green corn stage, ear length, number of grain rows per ear, ear weight, grain weight per ear and brix degrees. These results suggest that the yield and quality levels of the open-pollinated variety BRS Deni are similar to those of commercial hybrids for most of the relevant traits for sweet maize. BRS Deni is an option for super-sweet corn cultivation for coupling good ear and grain yield and quality with less expensive seed production, which may allow a reduction in the production cost of sweet corn. Thus, the variety BRS Deni is recommended for fresh ear production as well as for canning. However, sweet corn is still little known by Brazilian consumers, especially among the lower income population and in the interior of the country. The open-pollinated cultivar BRS Deni can stimulate the production of sweet corn by small farmers and in family agriculture, which can popularize green corn consumption. Thus, a new consumption habit may be created. The sale of fresh sweet corn ears on local markets may become an extra income source in small communities.

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