CROP BREEDING AND APPLIED BIOTECHNOLOGY

CULTIVAR RELEASE

Caviano: black bean cultivar with large root system and wide adaptability

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Abstract: *'Caviano' is a black bean cultivar recommended for Santa Catarina, for being highly adaptable to the main grain-producing regions of the state (mean grain yield 2315 kg ha^{-1}). Compared to previously released cultivars, Caviano has a larger root system and desirable characteristics for mechanical harvesting.*

Keywords: Phaseolus vulgaris *L., induced mutation, root distribution, adaptive traits.*

INTRODUCTION

For the Brazilian population, common bean (*Phaseolus vulgaris* L.) is a staple food and an important protein source. Currently, Brazil is considered the largest producer and consumer of common bean. On an estimated acreage of 2.8 million hectares, 3.1 million tons of grain are produced, equivalent to a grain yield of 1113 kg ha^{-1} (CONAB 2022). However, bean cultivation has been hampered by challenges that limit the productive potential (Daryanto et al. 2015). One of these is sensitivity to abiotic stresses in the extremely varied cultivation environments. On these grounds, all over the world root-related characteristics have become a research focus (Burridge et al. 2016, Burridge et al. 2019, Polania et al. 2017).

The root system is extremely important, since it determines the soil volume that can be explored and, consequently, the water and nutrient uptake, which are decisive for the adaptation of a genotype to an agroecosystem (Lynch 2018, Burridge et al. 2019). If this trait is not considered in breeding, the probability increases that specialized genotypes for highly favorable environments are developed that lack plasticity and, consequently, underperform under stress. Nevertheless, the evaluation of root characteristics has not yet become a routine procedure in common bean breeding programs.

One of the possibilities of generating useful genetic variability for root breeding is induced mutation (Rocha et al. 2010). This technique is useful in the area of plant breeding, for being capable of altering a genotype only slightly, in contrast to the procedures based on crosses between genetically distinct genotypes (Coimbra et al. 2007). Thus, the release of a cultivar from induced mutation, adapted to the local growing conditions and with a large root system, could be an alternative for common bean producers. In this sense,

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cultivar "Caviano" (in honor of the Center of Agroveterinary Science - CAV) was developed from the original cultivar IPR 88 Uirapuru by gamma irradiation. It has a mean grain yield above the state average, wide adaptability to the main common bean growing environments of the state and the particular advantage of an extensive root system.

BREEDING METHOD

Cultivar Caviano was developed from seeds of cv. IPR 88 Uirapuru, irradiated at the Oncology Unit of the Federal University of Pelotas (UFPel), Pelotas, Rio Grande do Sul, Brazil, in 2007. Seeds (250 g) of four cultivars (IPR 88 Uirapuru, IPR Chopim, BRS Pérola and Iapar 81) were irradiated with gamma rays of a mutagenic agent (Cobalt-60). First, the response to total absorbed doses of 0, 100, 200 and 400 grays (Gy) of all four cultivars was evaluated. The dose of 400 Gy was considered lethal, and only the populations irradiated at 100 and 200 Gy were maintained. In this way, eight M_1 populations (first mutant generation) were established. After irradiation, the M_1 seeds were washed under tap water and sown in the field, growing to approximately 600 plants per mutant population, on the fields of the Institute for Breeding and Molecular Genetics (IMEGEM) of the State University of Santa Catarina (UDESC-CAV), in Lages, Santa Catarina, Brazil, in the 2007/08 growing season.

The harvested M_1 plants and the generations in each subsequent selfed cycle were named in ascending order (subscript number). Since physiological and genetic effects were observed in the first generation, no selection was carried out. Thereafter, each M_1 population was bulk-harvested to generate the M_2 population (*Bulk* selection method). The procedure was repeated up to generation M_5 to establish populations with a high homozygosity level. In this period, the mutant populations and original cultivars were planted in replicated experiments, at commercial density (12 - 15 plants m^{-1} or about 200 plants $plot^{-1}$). The plants of these experiments were sampled to evaluate traits of agronomic interest such as: stem diameter, plant height, first pod insertion height, mean pod length, mean number of grains per pod and number of pods per plant. In addition, the plants were evaluated for root distribution in the field, which is still a rather rare measurement in common bean breeding programs. Two mutant populations had a particularly well-developed root system in the surface (0-10 cm) and intermediate (11-20 cm) soil layers (Rocha et al. 2010). To determine the traits mentioned above, 298 M_5 plants were harvested separately (50% of the seeds were stored away and 50% sown in individual rows in the next generation). Two additional selection cycles were carried out to eliminate phenotypically inferior plants.

In the 2012/13 growing season, the 77 best mutant lines (in generations M_5, M_6 or M_7) were selected for grain yield components. These mutant populations, together with other genotypes from the IMEGEM breeding program (25 segregating genotypes from hybridization) and 5 commercial cultivars (IPR 88 Uirapuru, IPR Chopim, BRS Pérola, Iapar 81 and BRS Campeiro) were included in a preliminary assay with 100 treatments in Lages, in the 2013/14 growing season. The experiment was arranged in Federer's augmented block design, with five replications. Each plot consisted of four 4-m rows, spaced 0.45m apart, with a total of 240 plants per plot or a density of 15 plants m^{-1}. Five plants were sampled to measure the adaptive traits and the grain yield produced on the evaluated plot area (3.6 m^2). To consider the traits simultaneously, the Smith and Hazel selection index was used, assigning weight to the selection criteria: plant height, first pod insertion height, stem diameter, number of pods per plant, number of grains per plant, 1000-grain weight and grain yield. Based on this index, 15 genotypes were selected, including a candidate line for registration, for which desirable traits for mechanical harvesting were recorded.

These genotypes together with commercial cultivars were further evaluated in preliminary tests over three growing seasons (2014/15 to 2016/17) in Lages/SC, to assess the agronomic performance and adaptability. The experiments were arranged in complete blocks with three replications. Each plot consisted of four 4-m rows, spaced 0.45m apart, with a total of 240 plants per plot or a density of 15 plants m^{-1}. At the end of the period, the fixed mutant population, resulting from irradiation of cv. IPR 88 Uirapuru at 100 Gy (experimental denomination UDESC|CAV17.EFM0006 "PMU_100 M8"), was indicated for the tests for Value for Cultivation and Use (VCU). In this way, it was included in the state evaluation network of plant lines, coordinated by the Company of Agricultural Research and Rural Extension of Santa Catarina (EPAGRI), in the growing seasons of 2018/19 and 2020/21, at six locations. Simultaneously, to validate the recommendation, the line was planted in a so-called Strip Test, on the property of a rural producer in the county of Campo Belo do Sul (high-altitude region of Santa Catarina), under the routine management practices of the farmer.

An evaluation of the criteria of Distinguishability, Homogeneity and Stability (DHS) confirmed that the mutant population UDESC|CAV17.EFM0006 has differentiating characteristics from the already registered original cultivar (IPR 88 Uirapuru) and that these traits are stable and homogeneous.

The population also proved to be well-adapted, mainly to the rainy season, and produced grain yields equivalent (5% probability) to the commercial cultivars tested (BRS Campeiro and IPR Tuiuiú). Owing to the superior agronomic traits and good performance recorded in the state evaluation network of plant lines, UDESC|CAV17.EFM0006 was registered in 2022 under the commercial name Caviano.

CHARACTERISTICS OF THE CULTIVAR

The plant architecture of cv. Caviano is semi-upright, the growth habit indeterminate and vine length short. The cultivar belongs to the black bean group and 1000 seeds weigh 200 g. The total cycle (from emergence to physiological maturity) lasts 88 days.

Root distribution in the field

Among the characters considered for the evaluation of cv. Caviano, root distribution is worth mentioning. This trait was measured in the field by the soil excavation method (Böhm 1979). By this methodology, perpendicular profiles (width 0.50 m, depth 0.30 m) were opened at a distance of 0.05 m from the plant row and the roots were exposed by cleaning with pocketknives and brushes. In the clean profile, a grid template (60 squares) of the same size as the trench was inserted immediately close to the roots. Subsequently, a picture of the template with the profile underneath was taken, for a quantitative assessment of root distribution, by assigning presence (1) or absence (0) of "root units" to each square (Figure 1).

Given the nature of the response variable (count data) and its respective distribution, the trait was extensively evaluated using Generalized Linear Models. Among the populations generated by induced mutation, cv. Caviano (PMU.100) stood

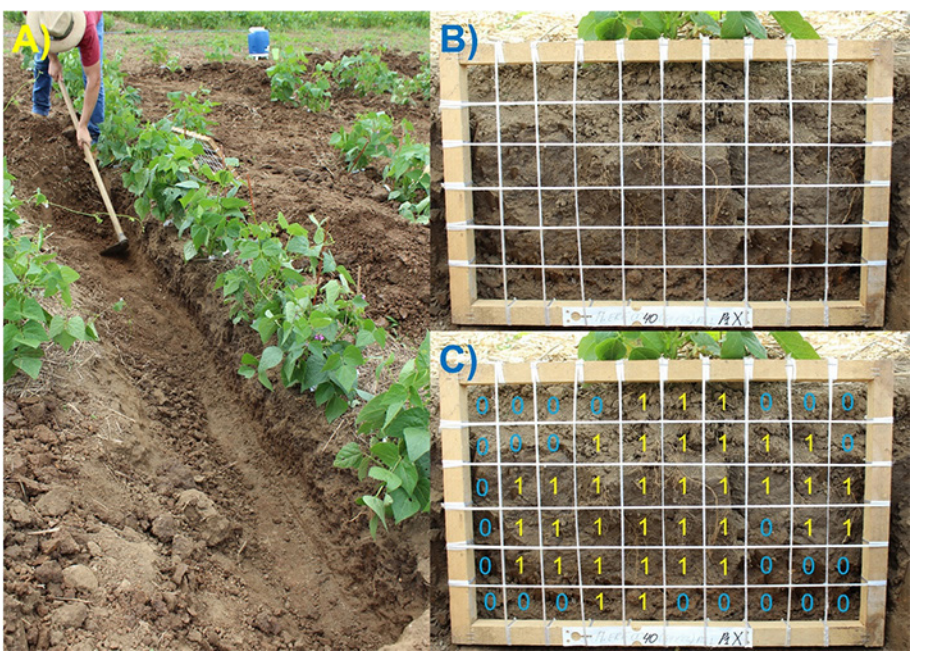

Figure 1. Steps to evaluate root distribution by the soil excavation method: a) Opening of a profile in the soil next to plants, perpendicular to plant row, leaving plants in the soil; b) Cleaning of profile inside by removing excess soil in-between roots and insertion of a grid template, with the same size as the profile (width 0.50, depth 0.30 m), with 60 squares; c) Photographing of the template + the profile underneath and determination of root presence or absence (1 or 0, respectively) in each square, indicating the root percentage per plant.

out with higher values of root distribution, at all depths assessed (Table 1). In fact, the observed values exceeded those of the original cultivar (IPR 88 Uirapuru), indicating positive effects of mutation on breeding for this trait.

Grain yield and genotypic adaptability

Cultivar Caviano had a mean grain yield of 2315 kg ha^{-1} and a yield potential of 4200 kg ha^{-1}. In the evaluation environments, the performance of the new black bean cultivar was statistically equivalent to that of the check cultivars (BRS Campeiro and IPR Tuiuiú), particularly in the rainy season (Table 2). In addition, in environments with a lower expected grain yield (dry season), the percentage reduction of cv. Caviano was lower (-16%) than that of cultivar SCS204 Predileto (-28%), which was the genotype with the highest grain yield of the commercial black bean cultivars. This result indicates the capacity of cv. Caviano to maintain the mean grain yield even under stressful growing conditions.

The positive results regarding the mean grain yield reflected in estimates considered ideal for the parameter genotype adaptability. Based on the values estimated by linear regression, Caviano was classified as a cultivar with wide adaptability (β = 1), as similarly observed for the check cultivars (Table 3). The significant regression deviation (σ^2_d) of cv. Caviano indicates that the genotypic performance may vary depending on the cultivation environment, thus reducing predictability (Vencovsky and Barriga 1992). However, this can be explained by the better root distribution of cv. Caviano. Under restrictive cultivation conditions, the cultivar tends to increase the root system to maintain the mean yield. For this reason, the grain yield differed between the "dry" and "rainy" environments. Under water stress, most leguminous crops develop mechanisms that favor an increase in the root system, to the detriment of shoot growth (Subbarao et al. 1995).

Table 1. Observed ($\bar{X}_0$) and transformed ($\bar{X}_T$) means (ρ = ln ($\bar{x}$ /1 - $\bar{x}$)) of the trait root distribution of cv IPR 88 Uirapuru and the populations derived by induced mutation.

Genotype	Soil depth (cm)					
	0-10		11-20		21-30	
	$\bar{X}_0$	$\bar{X}_T$	$\bar{X}_0$	$\bar{X}_T$	$\bar{X}_0$	$\bar{X}_T$
IPR 88 Uirapuru	0.827	1.564	0.169	-1.591	0.023	-3.746
Caviano (PMU.100)	1.000	-	0.525	0.100	0.050	-2.944
PMU.200	0.950	2.944	0.425	-0.302	0.000	-

Table 2. Grain yield (kg ha^{-1}) of cultivar Caviano and the check cultivars (BRS Campeiro and IPR Tuiuiú) for each evaluated location, season and growing season in the state of Santa Catarina

Location	Season	Growing season	Caviano	BRS Campeiro	IPR Tuiuiú
Campos Novos	rainy	2018/19	3180a	2845b	3526a
Chapecó	rainy	2018/19	2864a	2898a	2584b
Canoinhas	rainy	2018/19	2798a	2728a	2609a
Campos Novos	rainy	2020/21	3060a	3727a	3528a
Xanxerê	rainy	2020/21	4278a	4535a	4450a
Lages	rainy	2020/21	1255a	1357a	1743a
Ituporanga	dry	2018/19	1543a	1644a	1628a
Xanxerê	dry	2018/19	2205a	2332a	2524a
Chapecó	dry	2018/19	1757c	3013a	2215b
Ituporanga	dry	2020/21	1685a	1770a	1576a
Xanxerê	dry	2020/21	2148a	2059a	2059a
Chapecó	dry	2020/21	1013a	1098a	1264a
Mean rainy			2906a	3015a	3073a
Mean dry			1755a	1986a	1878a
Overall mean			2315a	2500a	2475a

Means followed by the same letter in a row do not differ statistically according to the Tukey test at 5% error probability.

Suitability for mechanical harvesting

Among the relevant traits for breeding, those related to plant architecture are essential to ensure an adequate functioning of mechanical harvesting. In this regard, the estimates for the agronomic traits first pod insertion height and stem diameter (21.3 and 6.5 mm, respectively) of cv. Caviano were significantly superior to those of the original cultivar IPR 88 Uirapuru (14.6 and 5.1 mm, respectively), at 5% error probability by the t test.

Table 3. Genotypic adaptability (β) and stability (σ^2_d) parameters estimated by linear regression

Cultivar	**Mean** (kg ha^{-1})	**β**	σ^2_d
Caviano	2315	0.9361	54073*
BRS Campeiro	2500	1.0086	25255
IPR Tuiuiú	2475	0.9663	1733

* Significant at 5% error probability by the t test.

BASIC SEED PRODUCTION

Cultivar Caviano was registered on February 1, 2022 by the National Register of Cultivars - Ministry of Agriculture, Livestock and Supply (RNC-MAPA), under number 48627. The Center of Agroveterinary Science (CAV) of the State University of Santa Catarina (UDESC) will be responsible for the production of basic seed.

CONCLUSIONS

Cultivar Caviano has a mean grain yield of 2315 kg ha^{-1} and is widely adaptable to the main bean-producing regions of Santa Catarina, above all in the rainy season. An advantageous trait of this black bean cultivar is the larger root system.

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