



BRS FC423: COMMON BEAN CULTIVAR WITH CARIOCA TYPE GRAIN WITH SLOW DARKENING, HIGH YIELD, AND HIGH RESISTANCE TO ANTHRACNOSE AND ROOT ROTS

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Abstract: BRS FC423 is a common bean cultivar with carioca type grain, slow grain darkening, and high sieve yield. It has a semi-early cycle (75 to 84 days); wide adaptation to different growing regions; high mean yield (2209 kg ha⁻¹), with prominent performance in the Central region (2217kg ha⁻¹); high yield potential (3843 kgha⁻¹); and resistance to root rots and anthracnose.

Keywords: *Phaseolus vulgaris*, root rots, anthracnose.

Introduction

In recent years, Brazil has been among the world's largest producers (2.7 million tons annually) and consumers of common bean (*Phaseolus vulgaris*) (EMBRAPA, 2022) (FAO, 2022). Among the diverse commercial groups of common bean, carioca (beige-colored seed coat with brown streaks) is noteworthy, as it represents around 70% of the consumer market (Pereira et al., 2021a).

The Brazilian market has become increasingly demanding in relation to the traits related to the commercial quality of the carioca grain, such as sieve yield, 100-seed weight, and grain color, among others. During the period between harvest and commercialization of the grain, the seed coat darkens in carioca type beans,

and that makes their commercial value decline; grain with lighter color has higher commercial value. Thus, the farmer must trade the product quickly, regardless of the market price.

In this respect, one of the most important demands has been obtaining new cultivars that have slow grain darkening, for this trait allows the farmer greater flexibility in the time to sell the grain. Various studies have already described important aspects of genetic control of grain darkening, and there already are some molecular markers available for carrying out marker-assisted selection (Junk-Knievel et al., 2008; Silva et al., 2008; Elsadr et al., 2011; Rodrigues et al., 2019; Alvares et al., 2019).

Different institutions have already obtained some carioca grain cultivars that



have slow darkening, such as BRSMG Madrepérola (Carneiro et al., 2012), IAC 2051 (Carbonell et al., 2021), and BRS FC415 (Pereira et al., 2022). However, these cultivars are still far fewer in number than those of normal darkening and, moreover, are agronomically inferior to the best cultivars that have normal grain darkening, especially in relation to plant architecture, resistance to lodging, and disease resistance.

Thus, BRS FC423 is a new cultivar, developed in a public-private partnership with 11 common bean seed-producing companies (Sementes JHS, Sementes Marambaia, Sementes Aliança, BJ Sementes, Sementes Orient, Sementes Campolina, Shancap Sementes, Di Solo Sementes, Sementes Lagoa Bonita, Menarin Sementes, and Cooprossel) with the aim of developing and identifying cultivars with specific adaptation to certain conditions.

BRS FC423 stands out for slow grain darkening, together with high sieve yield and high mean yield, with prominent performance in the Central region (region II of recommendation of common bean cultivars). In addition, BRS FC423 has high resistance to anthracnose and to root rots.

Breeding Methods Used

The initial step in development of the line has been described in detail by Silva et al. (2018). Line CNFC 16902 was originated from the cross between the cultivars BRS Notável and BRSMG Madrepérola, performed at Embrapa Arroz e Feijão in Santo Antônio de Goiás (GO) in 2009. Still in 2009, the F_1 generation of the population was sown under screened protection. In 2010, in the dry season, the population in the F_2 generation was sown in the field and harvested in bulk in Santo Antônio de Goiás. In the 2010 winter crop season, the population in the F_3 generation was sown in Santo Antônio de Goiás and harvested in bulk, with selection for resistance to lodging, color of the grain after storage (darkening), and grain yield. Also, in 2010, in Ponta Grossa (PR) in the rainy season, the F_4 generation was sown and harvested in bulk, with selection based

on the same criteria used in rainy/2010. In the 2011 winter season in Santo Antônio de Goiás, the F_5 generation was evaluated, and individual plants were harvested, with selection based on the same criteria used in winter/2010, obtaining the lines.

In another step of development, described in detail by Alvares et al. (2016), in the 2011 winter crop season in Santo Antônio de Goiás, the lines of the $F_{5:6}$ generation were multiplied to obtain a greater volume of seeds, including CNFC 16902. As of this step, evaluation in experiments with replications in multiple environments began. In 2012, the line CNFC 16902 was evaluated in the experiment for testing lines for darkening of the carioca grain; this experiment was composed of 225 treatments, consisting of 220 lines and five check cultivars (BRS Estilo, BRS Cometa, BRS Notável, BRS Sublime, and BRSMG Madrepérola). A 15×15 triple lattice design was used, and plots consisted of two 3-meter rows. The experiments were set up in three environments: Santo Antônio de Goiás (two experiments) and Brasília (DF) in the winter season. In these experiments, it was possible to evaluate grain yield, plant architecture, 100-seed weight, and grain color after storage (darkening). Joint analysis of these data led to selection of the CNFC 16902 line for participation in the advanced experiment for carioca grain darkening.

In 2013 and 2014, the CNFC 16902 line was evaluated in the advanced experiment for carioca grain darkening, composed of 49 treatments: 44 lines and five check cultivars (BRS Cometa, BRS Estilo, BRS Notável, BRS Sublime, and BRSMG Madrepérola) (Pereira et al., 2021b). A 7×7 triple lattice experimental design was used, with plots consisting of two 3-m rows. The experiments were conducted in 12 environments: Santo Antônio de Goiás (GO) in the 2013 winter, 2013 rainy, and 2014 winter crop seasons; Cáceres (MT) in the 2013 winter and 2014 winter crop seasons; Anápolis (GO) and Sete Lagoas (MG) in the 2013 winter crop season; Ponta Grossa (PR), Carira (SE), Belém do São Francisco (PE), and Brasília (DF) in the 2013 rainy crop season; and Uberlândia

(MG) in the 2013 dry crop season. These experiments allowed evaluation of yield, 100-seed weight, grain color after storage (darkening), cycle, plant architecture, and resistance to lodging.

Joint analysis of the data from the testing of lines in the carioca grain darkening experiment and the advanced testing in the carioca grain darkening experiment led to selection of the line CNFC 16902 for the Value for Cultivation and Use (Valor de Cultivo e Uso - VCU) trial, based on evaluation of 15 environments. In 2015, in the winter crop season in Santo Antônio de Goiás, seeds were multiplied to obtain sufficient seeds for preparing the VCU trials.

In 2016 and 2017, the line CNFC 16902 was evaluated in 86 trials composed of 20 treatments: 15 new lines with normal cycle and five check cultivars (BRS FC402, BRS Estilo, Pérola, IPR Bem-te-vi, and ANFC09). A randomized block experimental design was used with three replications and plots consisting of four 4-m rows, using the technologies recommended for the different environments and growing systems.

In these experiments, it was possible to evaluate the following aspects related to the grain: yield, sieve 12 (4.5mm) yield, 100-seed weight, color, uniformity, darkening, cooking time, and concentration of iron, zinc, and protein. In addition, a scoring scale from 1 (totally favorable phenotype) to 9 (totally unfavorable phenotype) (Melo, 2009) was used to evaluate plant architecture, resistance to lodging, and reaction to the following diseases: common bacterial blight (*Xanthomonas axonopodis* pv. *phaseoli*), bacterial wilt (*Curtobacterium flaccumfaciens* pv. *flaccumfaciens*), angular leaf spot (*Pseudocercospora griseola*), anthracnose (*Colletotrichum lindemutianum*), rust (*Uromyces appendiculatus*), Fusarium wilt (*Fusarium oxysporum* f. sp. *phaseoli*), root rots (*Fusarium solani* and *Rizoctonia solani*), bean common mosaic virus (BCMV), and bean golden mosaic virus (BGMV).

Of the 86 trials set up, 62 were harvested and achieved the standards of experimental quality necessary to be considered in the cul-

tivar registration process in relation to yield data. These 62 VCU trials were conducted in Region I (Santa Catarina, Paraná, São Paulo, and Mato Grosso do Sul) in the rainy and dry crop seasons; in Region II (Goiás, Distrito Federal, Mato Grosso, Espírito Santo, Minas Gerais, and Bahia) in the rainy, dry, and winter crop seasons; and in Region III (Sergipe, Alagoas, and Pernambuco) in the rainy crop season.

Grain yield was measured in kg ha⁻¹ and corrected to 13% grain moisture. Sieve yield was measured in the following manner: a 300-g sample was removed from each plot; then the sample was sieved in a sieve with oblong openings of 4.5 mm width; the seeds retained in the sieve were weighed; and the weight of the seeds retained in the sieve was divided by the initial weight of the sample. From the seeds retained, a new sample of 100 seeds was removed for weighing and obtaining the 100-seed weight. For determination of cooking time, a Mattson cooker was used. Analyses of protein concentration were carried out, determining the concentration of nitrogen by the micro-Kjeldahl method. Analyses of iron and zinc concentrations were performed by acid digestion of organic matter, according to the flame atomic absorption spectrophotometry technique.

Grain yield and yield potential

In these trials, the cultivar BRS FC423 (CNFC 16902) exhibited mean yield of 2209 kg ha⁻¹, higher than that of the check cultivars that also have slow grain darkening, BRS FC415 (2143 kg ha⁻¹) and ANFC09 (2097 kg ha⁻¹), and also BRS Estilo (2012 kg ha⁻¹) (Table 1). That represents 3.1% superiority in relation to the highest yielding check cultivar (BRS FC415) and 9.8% in relation to BRS Estilo. In relation to the different regions, BRS FC423 also had yield higher than the three check cultivars in Region II (Central) (2117 kg ha⁻¹), with 3.4% superiority compared to BRS FC415 and 7.7% compared to BRS Estilo. In Region I (Center South), BRS FC423 exhibited yield (2472 kg ha⁻¹) similar to that of the cultivars BRS FC415 and ANFC09, and 13.5% superior to that of

BRS Estilo. In Region III (Northeast), the yield of BRS FC423 (1838 kg ha⁻¹) was similar to that of BRS FC415 and 6.6% and 6.7% superior to that of ANFC09 and BRS Estilo, respectively.

The yield potential of BRS FC423, obtained from the mean value of the five trials in which this cultivar had the highest yields, was 3843 kg ha⁻¹, confirming the high genetic potential of the cultivar.

Table 1. Grain yield (kg ha⁻¹) of cv BRS FC423 compared to the mean of three check cultivars (BRS FC415, ANFC09, and BRS Estilo) in the Value for Cultivation and Use (VCU) trials, according to the recommended cultivation region and sowing time, from 2016 to 2017.

Region	Season	BRS FC423	BRS FC415	ANFC09	BRS Estilo	Number of environments
I	Rainy	2838 a	2883 a	2736 a	2797 a	17
	Dry	1694 a	1378 b	1335 b	861 c	8
	Overall	2472 a	2402 a	2288 a	2178 b	25
II	Rainy	2291 a	2223 a	2385 a	2247 a	12
	Dry	1707 a	1617 a	1560 a	1319 b	7
	Winter	2159 a	2095 a	2017 b	2024 b	19
	Overall	2117 a	2047 b	2049 b	1965 c	38
III	Rainy	1838 a	1790 a	1725 b	1723 b	8
Overall		2211 a	2143 b	2097 c	2012 d	71

Region I - SC, PR, MS, SP; Region II - MG, ES, GO, DF, MT; Region III - SE, PE. Mean values followed by the same letter in the rows do not differ statistically from each other according to the Scott-Knott method at 5% probability.

Commercial and nutritional seed quality

In relation to the traits of grain technological and industrial quality, the cultivar BRS FC423 has high 4.5-mm sieve yield (89%), similar to that of the cultivar ANFC09 and superior to that of the cultivars BRS Estilo and BRS FC415 (Table 2). BRS FC423 has a mean 100-seed weight of 24 grams, lower than that of the cultivars BRS Estilo, ANFC09, and BRS FC415. BRS Estilo is a reference on the market in relation to commercial grain quality. The grain of BRS FC423 is carioca type, with elliptical semi-full shape, without a shiny appearance. In relation to grain appearance, BRS FC423 has grain with slow darkening and coloring (light beige seed coat with brown streaks) that is not as light as BRS FC415 and ANFC09 (very light beige color

with light brown streaks). Nevertheless, the grain of BRSFC423 is very uniform in relation to color and is not grayish, as occurs with BRS FC415, ANFC09, and many of the cultivars that have slow darkening in some environmental conditions. The mean cooking time of BRS FC423 is 32 minutes, similar to that of the cultivars ANFC09 and BRS FC415. In relation to percentage of protein in the grain, BRS FC423 (24%) was similar to BRS FC402 and superior to the cultivars Pérola and BRS Estilo. Furthermore, BRS FC423 had an iron concentration (61 mg.kg⁻¹) in the grain superior to that of BRS Estilo and similar to the concentrations in the cultivars ANFC09 and BRS FC415. Zinc concentration (36 mg.kg⁻¹) was similar to the concentrations in BRS Estilo and BRS FC415 and lower than that in ANFC09.

Table 2. Comparison of grain traits of the common bean cultivar BRS FC423 with the check cultivars BRS FC415, ANFC09, and BRS Estilo.

Cultivar	CT (minutes)	PC (%)	FeC (mg kg ⁻¹)	ZnC (mg kg ⁻¹)	SY (%)	W100 (g)	COLOR	COLOR UNIFORMITY	DARK
BRS FC423	32 b	24 a	61 a	36 b	89 a	24 b	light beige	high	slow
BRS FC415	31 b	23 b	61 a	36 b	84 b	25 a	very light beige	medium	slow
BRS Estilo	26 a	22 b	55 b	34 b	82 c	25 a	very light beige	high	normal
ANFC09	31 b	27 a	59 a	38 a	87 b	25 a	very light beige	medium	slow

CT - cooking time; PC -protein concentration; FeC -iron concentration; ZnC -zinc concentration; SY - grain sieve yield (<4.5 mm); W100 - 100-seed weight; COLOR -predominant color; DARK - darkening. Mean values followed by the same letter in the columns do not differ statistically from each other according to the Scott-Knott method at 5% probability.

Other traits

In the field experiments, BRS FC423 proved to be resistant to bean common mosaic virus and to rust, and moderately resistant to anthracnose and root rots (Table 3). However, it proved to be susceptible to the bean golden mosaic virus, Fusarium wilt, bacterial wilt, common bacterial blight, and angular leaf spot. In general, up to the present time, the cultivars with slow darkening of grain available on the market do not have a very high general level of resistance to the diseases. In that respect, BRS FC423 had greater resistance to anthracnose than BRS FC415 and ANFC09 did, resistance to root rots similar to that of BRS FC415, and

lower resistance to Fusarium wilt than BRS FC415.

BRS FC423 has a semi-early cycle (between 75 and 84 days from emergence to physiological maturity), a shorter cycle than that of the check cultivars. The plants are shrub like, with an indeterminate type III growth habit. In relation to plant architecture, BRS FC423 is semi-prostrate and has intermediate resistance to lodging, and it is adapted to mechanical harvest, including direct harvest, in a way similar to BRS FC415 and ANFC09, but inferior to that of BRS Estilo. The flowers are white, and at physiological maturity and harvest, the pods are yellowish.

Table 3. Agronomic traits and disease reaction traits of the cultivar BRS FC423 compared to the carioca grain cultivars BRS FC415, BRS Estilo, and ANFC09.

Cultivar	Cycle	ARCH	LOD	AN	CBB	RU	ALS	BCMV	BGMV	FW	CUR	RR
BRS FC423	SE	Semi-Prostrate	I	MR	S	MR	S	R	S	S	S	MR
BRS FC415	N	Semi-Upright	I	I	S	MR	S	R	S	MR	S	MR
BRS Estilo	N	Upright	MR	I	S	MR	S	R	S	S	S	S
ANFC09	N	Semi-Upright	I	I	S	MR	S	SI	S	S	S	I

ARCH –plant architecture; LOD –resistance to lodging; AN –anthracnose; CBB –common bacterial blight; RU –rust; ALS – angular leaf spot; BCMV –bean common mosaic virus; BGMV –bean golden mosaic virus; FW – Fusarium wilt; CUR – bacterial wilt; RR – root rots; N –normal cycle; SE –semi-early cycle; R –resistant; MR –moderately resistant; I –intermediate; S –susceptible

Seed production

BRS FC423 was registered in 2022 under number 51154, and the request for protection has already been submitted, with the Brazilian Ministry of Agriculture (Ministério da Agricultura, Pecuária e Abastecimento – MAPA). The production of seeds with these genetics will be under the responsibility of Embrapa, and production to meet the demand from grain producers will be carried out exclusively by 11 seed production companies (Sementes JHS, Sementes Marambaia, Sementes Aliança, BJ Sementes, Sementes Orient, Sementes Campolina, Shancap Sementes, Di Solo Sementes, Sementes Lagoa Bonita, Menarin Sementes, and Cooprossel), who have signed a public-private partnership contract for the development of new common bean cultivars with specific adaptation to a determined region, biome, sowing season, climate condition, or production system.

Conclusions

Prominent traits of BRS FC423 are slow grain darkening, high sieve yield, and a semi-early cycle. BRS FC423 also has high mean yield, especially in the Central region (Region II), exceeding the yield of the check cultivars that also have slow darkening. In addition, BRS FC423 has an excellent level of resistance to anthracnose and to root rots.

Based on its performance, BRS FC423 was registered for the following crop seasons: rainy and dry in Region I (Mato Grosso do Sul, Paraná, Santa Catarina, São Paulo, and Rio Grande do Sul); rainy, dry, and winter in Region II (Minas Gerais, Goiás, Distrito Federal, Mato Grosso, Tocantins, Rio de Janeiro, Espírito Santo, Bahia, and Maranhão); and rainy in Region III (Sergipe, Alagoas, Pernambuco, Rio Grande do Norte, Piauí, Ceará, and Paraíba).

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