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BRS FC415: COMMON BEAN CULTIVAR WITH HIGH YIELD, COMMERCIAL QUALITY, SLOW SEED COAT DARKENING, AND RESISTANCE TO SOIL PATHOGENS

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Abstract: BRS FC415 is a common bean cultivar with *carioca* grain type, high commercial quality, and slow seed coat darkening. It has wide adaptation to different production regions, high mean yield (2,310 kg ha^{-1}), high yield potential (3,901 kg ha^{-1}), and resistance to Fusarium wilt, root rots, and anthracnose.

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

Introduction

In recent years, Brazil has occupied one of the first places in the production (2.7 million metric tons annually) and consumption of common bean (dry edible bean) (*Phaseolus vulgaris*) in the world (EMBRAPA, 2022) (FAO, 2022). The *carioca* (cream-colored seed coat with brown streaks) bean is prominent among the diverse commercial groups of common beans, as it is preferred by most consumers in Brazil and occupies around 70% of the consumer market (Pereira et al., 2021).

In addition, over the past few years, the Brazilian market has become more and more demanding regarding characteristics related to the commercial quality of bean grain, such as sieved grain yield, 100-seed weight, and seed coat color, among other traits. In the period between harvest and sale of the beans, the beige or cream-colored shade of the seed coat becomes darker in carioca beans, and this decreases the commercial value of the beans, because beans with a lighter color have higher commercial value. This makes the farmer market the product rapidly, regardless of the market price.

In this regard, one of the most important demands has been that of obtaining new cultivars that have slow seed coat darkening, because this characteristic provides greater flexibility to the farmer in the time of sale of the crop. Various studies have already described important aspects of genetic control of seed coat darkening and there are already some molecular markers available for performing marker assisted selection (Junk-Knievel et al., 2008; Silva et al., 2008; Elsadr et al., 2011; Rodrigues et al., 2019; Alvares et al., 2019).

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There are already some cultivars of the carioca commercial group obtained by different institutions that have slow darkening, such as BRSMG Madrepérola (Carneiro et al., 2012), ANFC 09, TAA Dama, and IAC 2051 (Carbonell et al., 2021). However, these cultivars are still much fewer in number than those of normal darkening, and moreover, are agronomically inferior to the best cultivars that have normal seed coat darkening, especially in relation to plant architecture, resistance to lodging, and resistance to diseases caused by soil pathogens.

BRS FC415 stands out through its wide adaptation to different production regions, with high yield and excellent grain commercial quality, especially regarding slow seed coat darkening. In addition, it has moderate resistance to Fusarium wilt and root rots, which allows it to be used in older crop areas under center pivot irrigation; it is also moderately susceptible to anthracnose.

Breeding methods

BRS FC415 originated from a cross between the cultivar BRS Horizonte and the line LM202206076, the latter exhibiting slow seed coat darkening. The cross was made at Embrapa Arroz e Feijão in Santo Antônio de Goiás, GO, Brazil, in 2004. In 2005, the F_1 generation of the population was sown under protective screening. Also in 2005, in the winter season, the population in the F_2 generation was sown in the field and harvested in bulk in Santo Antônio de Goiás, with selection for plant architecture, lodging, and seed color, darkening, size, and yield. In 2006 dry season/2006, the population in the F_3 generation was sown in Ponta Grossa and harvested in bulk, with selection for seed color, darkening, and size, plant architecture, lodging, and disease resistance (anthracnose, angular leaf spot, bacterial wilt, and rust). Also in 2006, in Ponta Grossa, in the rainy season, the F_4 generation was sown and harvested in bulk, with selection based on reaction to diseases (anthracnose and common bacterial blight), plant architecture, lodging, and seed color, darkening, and size. In 2007 winter season in Santo Antônio de Goiás, the F_5 generation was evaluated and harvested in bulk, with selection based on plant architecture, lodging, and seed color, darkening, size, and yield. Also in 2007, in the rainy season in Ponta Grossa, the F_6 generation was evaluated and individual plants were selected based on reaction to diseases (anthracnose and common bacterial blight), plant architecture, lodging, and seed color, darkening, and size in order to obtain lines.

In 2008, in the winter season, the lines in the $F_{6:7}$ generation were sown in Santo Antônio de Goiás in individual rows, and selection was made based on plant architecture, lodging, and seed color, darkening, size, and yield, selecting the line LMC 208303561. From this step on, this line received the name CNFC 15826 and the step of evaluation in experiments with replications began, in multiple environments.

In 2010, the CNFC 15826 line was evaluated in the carioca progeny test, composed of 170 treatments, consisting of 163 new lines and seven check cultivars (BRS Estilo, BRS Cometa, Pérola, BRS Pontal, IAC Alvorada, BRSMG Majestoso, and IPR Juriti). A randomized block design was used with three replications and plots of two 4-m rows. The experiments were set up in two environments: Ponta Grossa, in the dry season, and Santo Antônio de Goiás, in the winter season. In these experiments, it was possible to evaluate grain yield, plant architecture, resistance to lodging, and reaction to diseases (anthracnose, angular leaf spot, and common bacterial blight). Joint analysis of these data led to selection of the CNFC 15826 line for participation in the preliminary carioca experiment.

In 2011, the CNFC 15826 line was evaluated in the preliminary carioca experiment, composed of 68 treatments, consisting of 63 new lines and five

check cultivars (BRS Estilo, BRS Cometa, Pérola, BRS Notável, and IAC Alvorada). A randomized block experimental design was used with three replications and plots of two 4-m rows. The experiments were conducted in six environments: Santo Antônio de Goiás (GO) in the winter season; Ponta Grossa (PR) and Carira (SE) in the rainy season; and Ponta Grossa, Lavras (MG), and Santo Antônio de Goiás in the dry season. In these experiments, it was possible to evaluate grain yield, cycle, plant architecture, resistance to lodging, and reaction to diseases (anthracnose, common bacterial blight, angular leaf spot, and bacterial wilt). Joint analysis of the data obtained in the preliminary carioca experiment, together with the data obtained in the carioca progeny test experiment, led to selection of the CNFC 15826 line for participation in the intermediate carioca experiment, based on results from eight environments.

In 2013, the CNFC 15826 line was evaluated in the intermediate carioca experiment composed of 38 treatments, consisting of 32 new lines and six check cultivars (BRS Cometa, BRS Estilo, BRS Notável, BRS Ametista, IPR 139, and Pérola). A randomized block experimental design was used with three replications and plots of two 4-m rows. The experiments were conducted in eleven environments: Santo Antônio de Goiás (GO) in the winter seasons (three trials); Ponta Grossa (PR) in the rainy and dry seasons; Carira (SE) and Paripiranga (BA) in the rainy season; and Brasília (DF), Lavras (MG), Uberlândia (MG), and Sete Lagoas (MG) in the winter season.

In these experiments, it was possible to evaluate grain yield, sieve grain yield 12 (4.5mm), color, darkening, shape, uniformity, concentrations of iron, zinc, crude fiber, and protein, cooking time, 100-seed weight, cycle, plant architecture, resistance to lodging, and reaction to diseases (anthracnose, common bacterial blight, angular leaf spot, Fusarium wilt, and bacterial wilt). Joint analysis of the data of the intermediate, preliminary, and carioca progeny test experiments led to selection of the CNFC 15826 line for the carioca Value for Cultivation and Use (VCU) trial, based on evaluation of 20 environments. In 2015, in the winter season in Santo Antônio de Goiás, seeds were multiplied to obtain enough for preparation of VCU trials. In 2016 and 2017, the CNFC 15826 line was evaluated in 86 carioca VCU experiments, composed of 20 treatments, consisting of 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 of four 4-m rows, using the technologies recommended for the different environments and cropping systems.

In these experiments, it was possible to evaluate the following aspects related to the grain: grain yield, sieve yield (4.5mm), 100-seed weight, color, darkening, cooking time, and concentration of iron, zinc, and protein. The following aspects were also evaluated on a scoring scale ranging from 1 (totally favorable phenotype) to 9 (totally unfavorable phenotype) (Melo, 2009): plant architecture, resistance to lodging, and reaction to the 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, Rizoctônia solani*), bean common mosaic virus (BCMV), and bean golden mosaic virus (BGMV).

Grain yield was measured in kg $ha^{-1}$and corrected to 13% grain moisture. Sieved grain yield was measured as follows: a 300-g sample was removed from each plot; this sample was then passed through a sieve with oblong openings of 4.5 mm thickness; the seeds retained in the sieve were weighed; 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. A Mattson cooker was used for determination of cooking time. Protein concentration was analyzed through determination of the nitrogen concentration by the micro-Kjeldahl method. Concentrations of iron and zinc were analyzed by acid digestion of organic matter, in accordance with the flame atomic absorption spectrometry technique.

Grain yield and yield potential

Of the 86 experiments set up, 62 were harvested and achieved the necessary standards of experimental quality to be considered in the cultivar 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 seasons, in Region II (Goiás, Distrito Federal, Mato Grosso, Espírito Santo, Minas Gerais, and Bahia) in the rainy, dry, and winter seasons, and in Region III (Sergipe, Alagoas, and Pernambuco) in the rainy season. In these trials, the cultivar BRS FC415 (CNFC 15826) had mean yield of 2,310 kg ha^{-1}, higher than that of the check cultivars BRS Estilo (2,212 kg ha^{-1}) and ANFC09 (2,256 kg ha^{-1}), which also have slow grain darkening, with superiority of 4.4% and 2.4%, respectively (Table 1). This result was repeated in Region I, with 4.9% and 6.3% superiority. In Regions II and III, BRS FC415 had yields similar to that of ANFC09 and higher than the yields of BRS Estilo (3.6% and 7.9%, respectively).

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

Region	Season	BRS FC415 (kg ha^{-1})	BRS Estilo (kg ha^{-1})	ANFC09 (kg ha^{-1})	Number of environments
I	Rainy	3,016 a	2,855 b	2,834 b	16
	Dry	1,615 a	1,615 a	1,531 b	5
	Overall	2,682 a	2,560 b	2,524 b	21
II	Rainy	2,443 c	2,518 b	2,618 a	10
	Dry	1,720 a	1,452 b	1,780 a	6
	Winter	2,166 a	2,071 b	2,081 b	18
	Overall	2,169 a	2,093 b	2,186 a	32
III	Rainy	1,882 a	1,745 b	1,790 a	7
Overall	**-**	**2,310 a**	**2,212 c**	**2,256 b**	**62**

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

The yield potential of BRS FC415, obtained from the mean of the five experiments in which this cultivar had the highest yields, was 3,915 $kgha^{-1}$. This estimate shows that the cultivar has high genetic potential and that if the environment is favorable and there are good growing conditions, high yields can be achieved.

Commercial and nutritional seed quality

In relation to the characteristics of technological and industrial quality of the grain, the cultivar BRS FC415 has good grain sieved yield (84%), higher than that of the cultivar BRS Estilo and lower than that of ANFC09 (Table 2). BRS FC415 has a mean 100-seed weight of 25.3 grams, similar to that of the cultivar ANFC09 and higher than that of BRS Estilo, which is reference in the market in relation to commercial quality of the grain. The grain is of the carioca type (cream-colored with brown streaks), of elliptical shape, and without shine. In relation to grain appearance, BRS FC415 proved to be similar to ANFC09, with very light cream color and light brown streaks and slow seed coat darkening.

Table 2. Comparison of grain traits of common bean cultivar BRS FC415 with the check cultivars ANFC09, BRS Estilo, and BRS FC402.

Cultivar	CT (min.)	PC (%)	FeC (mg kg^{-1})	ZnC (mg kg^{-1})	SY (%)	W100 (g)	COLOR	DARK
BRS FC415	31 b	23 b	61 b	36 b	84 b	25.3 a	very light beige	slow
ANFC09	31 b	27 a	59 b	38 a	87 a	25.3 a	very light beige	slow
BRS Estilo	26 a	22 b	55 b	34 b	82 c	24.9 b	very light beige	normal
BRS FC402	32 b	25 a	66 a	37 a	72 d	22.2 c	light beige	normal

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

Mean cooking time of BRS FC415 is 31 minutes, similar to that of the cultivar ANFC09 and higher than that of BRS Estilo. In relation to protein percentage in the grain, BRS FC415 (22.9%) was similar to BRS Estilo and less than ANFC09. Furthermore, BRS FC415 had iron concentrations (61.3 mg kg^{-1}) in the grain similar to that of the cultivars ANFC09 and BRS Estilo. The zinc concentration (36.3 mg kg^{-1}) was similar to that of BRS Estilo and lower than that of ANFC09.

Other traits

Under artificial inoculation, the BRS FC415 cultivar is resistant to bean common mosaic virus. In field experiments, it proved to be moderately resistant to Fusarium wilt and to root rots and moderately susceptible to anthracnose (Table 3). However, it proved to be susceptible to bean golden mosaic virus, common bacterial blight, bacterial wilt, and angular leaf spot. In general, up to the present time, the cultivars with slow seed coat darkening available on the market do not have a very high general level of disease resistance and are quite susceptible to soil pathogens. In this respect, BRS FC415 stands out from the other cultivars that have slow seed coat darkening since it has resistance to anthracnose and to rust similar to the resistance shown by ANFC09. It also has an excellent level of resistance to soil pathogens that cause Fusarium wilt and root rots; it is more resistant than ANFC09 and similar to BRS FC402, which is a standard of resistance to these diseases but that has normal seed coat darkening.

Table 3. Agronomic traits and disease reaction traits of cultivar BRS FC415 in comparison with the carioca cultivars BRS Estilo, BRS FC402, and ANFC09

Cultivar	Cycle	ARCH	AN	LOD	CBB	RU	ALS	BCMV	BGMV	FW	CUR	RR
BRS FC415	N	Semi-upright	MS	MS	S	MR	S	R	S	MR	S	MR
ANFC09	N	Semi-upright	MS	MS	S	MR	S	SI	S	S	S	MS
BRS Estilo	N	Upright	MS	MR	S	MR	S	R	S	S	S	S
BRS FC402	N	Semi-prostrate	MR	MS	MS	MR	S	R	S	MR	S	MR

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; R – resistant; MR – moderately resistant; MS – moderately susceptible; and S – susceptible.

BRS FC415 has a normal cycle (from 85 to 94 days from emergence to physiological maturity), similar to that of the check cultivars. The plants are shrub type, with a type II indeterminate growth habit. In relation to plant architecture, BRS FC415 is semi-upright, has good resistance to lodging, and is adapted to mechanical harvest, including direct harvest, similar to ANFC09. Its flowers are white and at physiological maturity and harvest, the pods are yellowish.

Seed production

BRS FC415 was registered in 2020 under number 45284 and protected in 2021 under number 20210143 with the Brazilian Ministry of Agriculture (Ministério da Agricultura, Pecuária e Abastecimento – MAPA).The production of genetic seeds will be under the responsibility of Embrapa, and production to meet demand from growers will be performed by partner seed production companies selected through a public notice for technical cooperation.

Conclusions

BRS FC415 stands out through its high yield and excellent grain commercial quality, and particularly its slow seed coat darkening. In addition, it has moderate resistance to Fusarium wilt and root rots, which means it can be used in older crop areas under center pivot irrigation; it also has moderate susceptibility to anthracnose.

Based on its performance, BRS FC415 will be registered for the rainy and dry seasons in Region I (Mato Grosso do Sul, Paraná, Santa Catarina, São Paulo, and Rio Grande do Sul); for the rainy, dry, and winter seasons in Region II (Goiás, Distrito Federal, Mato Grosso, Tocantins, Rio de Janeiro, and Espírito Santo); for the rainy and winter seasons in Bahia and Maranhão; and for the rainy season in Region III (Sergipe, Alagoas, Pernambuco, Rio Grande do Norte, Piauí, Ceará, and Paraíba).

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