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BRS FC424: Carioca common bean cultivar with high yield, commercial quality, and disease resistance

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Abstract: BRS FC424 has high yield, especially in the Center-South region of Brazil (2,496 kg ha^{-1}), and excellent bean commercial quality (color, uniformity, 100-seed weight, and sieve yield). In addition, BRS FC424 has intermediate resistance to various diseases, such as root rots, Fusarium wilt, and anthracnose, and moderate resistance to angular leaf spot.

Keywords: *Phaseolus vulgaris*, root rot, Fusarium wilt, anthracnose, angular leaf spot.

Introduction

Common bean (*Phaseolus vulgaris* L.) is widely grown and consumed in Brazil and has high socioeconomic value. It is part of production systems of small, medium, and large rural growers in different regions and crop seasons.

Brazil has been among the largest producers and consumers of common bean worldwide, with production of 2.3 million metric tons on 1.5 million hectares annually (EMBRAPA, 2024; FAO, 2024). Among the diverse common bean commercial groups, the Carioca bean (beige-colored seed coat with brown streaks) is noteworthy, as it represents around 70% of the consumer market in Brazil (Pereira et al., 2021a).

The Brazilian market has become increasingly demanding regarding traits related to the agronomic and commercial quality of the Carioca bean grain, with a preference for a very light beige seed coat. Therefore, the common bean breeding program of Embrapa Arroz e Feijão (Embrapa Rice and Bean) focuses on obtaining cultivars with high yield potential, greater disease resistance, and upright stand, which allows mechanized harvest, so that farmers can offer a better-quality product to the final consumer and achieve higher yields from the crop.

In recent years, Embrapa has released some Carioca bean cultivars on the market that have beans with very

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light beige-colored seed coats and normal bean darkening, such as BRS Estilo (Melo et al., 2010), which has high sieve yield and 100-seed weight and intermediate resistance to anthracnose; BRS FC310 (Melo et al., 2022a), which has high resistance to anthracnose and common bacterial blight and intermediate resistance to Fusarium wilt; and BRS FC414 (Melo et al., 2022b), which has high sieve yield and 100-seed weight and intermediate resistance to Fusarium wilt and anthracnose. Nevertheless, none of them combine resistance to root rots, Fusarium wilt, anthracnose, and angular leaf spot.

Within this scenario, BRS FC424 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 specifically adapted to certain conditions.

BRS FC424 has high yield, especially in the Center-South region of Brazil (2,496 kg ha^{-1}), as well as excellent commercial quality of the beans regarding color, uniformity, 100-seed weight, and sieve yield. Furthermore, BRS FC424 has intermediate resistance to several diseases, such as root rots, Fusarium wilt, and anthracnose, and moderate resistance to angular leaf spot. This cultivar should assist in reducing the use of pesticides and, consequently, in decreasing the impact on the environment and human health, contributing to increased sustainability in agricultural production.

Breeding methods used

CNFC 15853 originated from a cross between the cultivars BRS Sublime and BRS Pontal, carried out at Embrapa Arroz e Feijão in Santo Antônio de Goiás, GO, Brazil, in 2004. Also in 2004, the F_1 generation of the population was sown in a screened enclosure. In the 2005 dry crop season, the population in the F_2 generation was sown in the field and harvested in bulk in Ponta Grossa, PR, with selection for bean color, size, and yield, plant architecture, resistance to lodging, and resistance to diseases (anthracnose, angular leaf spot, bacterial wilt, and rust). In the 2005 rainy crop season, the population in the F_3 generation was sown in Ponta Grossa and harvested in bulk, with selection based on reaction to diseases (anthracnose and common bacterial blight), plant architecture, resistance to lodging, and bean color, size, and yield. In 2006, in Santo Antônio de Goiás, the F_4 generation was evaluated and harvested in bulk, with selection based on plant architecture, resistance to lodging, and bean color, size, and yield. In the 2007 dry crop season in Ponta Grossa, the F_5 generation was evaluated and harvested in bulk, with selection for bean color, size, and yield, plant architecture, resistance to lodging, and resistance to diseases (anthracnose, angular leaf spot, bacterial wilt, and rust). Also in 2007, in the rainy crop 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, resistance to lodging, and bean color, size, and yield to obtain lines.

In the 2008 winter crop season, the progenies in the $F_{6:7}$ generation were sown in Santo Antônio de Goiás in individual rows, and selection was made based on plant architecture, resistance to lodging, and bean color, size, and yield. In the 2009 dry crop season in Ponta Grossa, the $F_{7:8}$ lines were evaluated and selected for bean color, size, and yield, plant architecture, resistance to lodging, and resistance to diseases (anthracnose, an-

gular leaf spot, bacterial wilt, and rust), selecting the line that received the name CNFC 15853. From this step on, evaluation began in experiments with replications in multiple environments.

In 2010, the CNFC 15853 line was evaluated in the Carioca progeny test experiment, consisting of 170 treatments, with 163 new lines and seven check cultivars (BRS Estilo, BRS Cometa, Pérola, BRS Pontal, IAC Alvorada, BRSMG Majestoso, and IPR Juriti). A randomized block experimental design was used with three replications and plots of two 4-meter rows. The experiments were set up in two environments: Ponta Grossa, in the dry crop seasons, and in Santo Antônio de Goiás, in the winter crop season. In these experiments, it was possible to evaluate bean yield, plant architecture, resistance to lodging, and reaction to diseases (anthracnose, angular leaf spot, and common bacterial blight). Combined analysis of these data led to selection of the CNFC 15853 line for participation in the preliminary trial.

In 2011, the CNFC 15853 line was evaluated in the preliminary Carioca experiment, consisting of 68 treatments, with 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-meter rows. The experiments were conducted in six environments: Santo Antônio de Goiás (GO), in the winter crop season; Ponta Grossa (PR) and Carira (SE), in the rainy crop season; and Ponta Grossa (PR), Lavras (MG), and Santo Antônio de Goiás (GO), in the dry crop season. In these experiments, it was possible to evaluate bean yield, plant cycle, plant architecture, resistance to lodging, and reaction to diseases (anthracnose, common bacterial blight, angular leaf spot, and bacterial wilt). Combined analysis of the data obtained in the preliminary Carioca experiment, together with the data obtained in the progeny test experiment, led to selection of the CNFC 15853 line for participation in the intermediate Carioca experiment.

In 2013, the CNFC 15853 line was evaluated in the intermediate Carioca experiment, consisting of 38 treatments, with 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-meter rows. The experiments were conducted in eleven environments: Santo Antônio de Goiás (GO), in the winter crop seasons (three trials); Ponta Grossa (PR), in the rainy and dry crop seasons; Carira (SE) and Paripiranga (BA), in the rainy crop season; and Brasília (DF), Lavras (MG), Uberlândia (MG), and Sete Lagoas (MG) in the winter crop season. In these experiments, it was possible to evaluate yield, sieve yield (sieve 12 – 4.5 mm), bean color, shape, and uniformity, and 100-seed weight. In addition, evaluation was made of plant cycle, plant architecture, resistance to lodging, and reaction to diseases (anthracnose, angular leaf spot, common bacterial blight, bacterial wilt, and Fusarium wilt).

Combined analysis of the data from the progeny and preliminary and intermediate Carioca test experiments led to selection of the CNFC 15853 line for the Value for Cultivation and Use Experiment (VCU), based on evaluation of 20 environments. In the 2015 winter crop season in Santo Antônio de Goiás (GO), seeds were multiplied to obtain a sufficient number to prepare the VCU trials.

In 2016 and 2017, the CNFC 15853 line was evaluated in 86 trials consisting of 20 treatments, with 15 new lines with a 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-meter rows, using the technologies recommended for the different environments and crop systems.

In these experiments, it was possible to evaluate the following aspects related to the grain: yield, sieve yield (sieve 12 – 4.5 mm), 100-seed weight, color, uniformity, shape, seed coat darkening, cooking time, and concentration of iron, zinc, and protein. Furthermore, a scoring scale ranging from 1 (totally favorable phenotype) to 9 (totally unfavorable phenotype) (Melo, 2009) was used to evaluate plant architecture, resistance to lodging, and reaction to 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 experiments set up, 71 were harvested and achieved the standards of experimental quality necessary to be considered in the cultivar registration process in relation to yield data. These 71 VCU experiments 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, and Minas Gerais) 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 as follows: a 300 g sample was taken from each plot. The sample was then sieved through a mesh 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 100-seed sample was taken for weighing to obtain the 100-seed weight. A Mattson cooker was used to determine cooking time. Protein concentration was analyzed, determining nitrogen content by the micro-Kjeldahl method. Iron and zinc concentrations were analyzed by acid digestion of organic matter, according to the flame atomic absorption spectrophotometry technique.

Grain yield and yield potential

In these experiments, the cultivar BRS FC424 had a mean yield of 2,190 kg.ha^{-1}, similar to Pérola (2,192 kg.ha^{-1}), 8.8% higher than BRS Estilo (2,012 kg.ha^{-1}), and 4.8% higher than BRS FC414 (2,091 kg.ha^{-1}) (Table 1).

That also occurred in Regions I (Center-South) and II (Northeast), with mean yield of 2,496 kg.ha^{-1} and 14.1% average superiority in relation to BRS Estilo and BRS FC414 in the Center-South Region. In the Northeast Region, the mean yield of BRS FC424 was 1,895 kg.ha^{-1}, an average of 8% higher than BRS Estilo (1,723 kg.ha^{-1}) and BRS FC414 (1,787 kg.ha^{-1}). In Region II (Central), BRS FC424 had a mean yield of 2,055 kg.ha^{-1}, which was 2.8% lower than Pérola (2,115 kg.ha^{-1}) and 3.5% higher than the mean yield of BRS FC414 (2,005 kg.ha^{-1}) and BRS Estilo (1,965 kg.ha^{-1}).

The maximum productivity in VCU experiments, obtained from the average of the five VCU experiments in which this cultivar presented the highest yield, was 4,239 kg ha^{-1}. This estimate shows that the cultivar has high genetic potential and that if the environment is favorable and there are good growing conditions, even higher yields can be achieved, since there

is no disease control in VCU experiments. The expected average yield in a crop with a good technological level and good environmental conditions of BRS FC424 is 4,000 kg ha^{-1}. The productive potential, in optimal conditions, is 6,000 kg ha^{-1}.

Table 1. Grain yield (kg ha^{-1}) of the cultivar BRS FC424 compared to the three check cultivars (BRS FC414, BRS Estilo, and Pérola) in the Value for Cultivation and Use (*Valor de Cultivo e Uso* - VCU) experiments, according to the regions of recommendation of cultivars and to the sowing seasons in 2016 and 2017.

Region	Crop season	BRS FC424	BRS FC414	BRS Estilo	Pérola	Number of environments
I	Rainy	3,068 a	2,663 b	2,797 b	2,918 a	17
	Dry	1,279 a	1,209 a	861 b	1,284 a	8
	Mean	2,496 a	2,198 b	2,178 b	2,395 a	25
II	Rainy	2,456 a	2,241 b	2,247 b	2,348 a	12
	Dry	1,482 b	1,692 a	1,319 c	1,700 a	7
	Winter	2,012 b	2,032 b	2,024 b	2,120 a	19
	Mean	2,055 b	2,005 c	1,965 c	2,115 a	38
III	Rainy	1,895 a	1,787 a	1,723 b	1,906 a	8
Overall mean	**-**	**2,192 a**	**2,091 b**	**2,012 c**	**2,190 a**	**71**

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

Grain quality

Regarding the technological and industrial quality traits of the grain, the cultivar BRS FC424 has high sieve yield (sieve 12 – 4.5 mm) (85%), similar to that of BRS FC414 and higher than that of the check cultivars BRS Estilo and Pérola, which are market standards for this trait (Table 2). BRS FC424 has mean 100-seed weight of 25 grams, similar to that of the cultivar BRS Estilo and less than that of the BRS FC414 and Pérola cultivars, which have a 100-seed weight higher than the mean of the cultivars available on the market. The beans are Carioca type, with a flattened elliptical shape and without a shiny appearance. The visual appearance of the BRS FC424 beans is a very light cream color with light brown streaks and normal seed coat darkening, similar to the BRS Estilo cultivar, which is a commercial market standard for these traits. The mean cooking time of BRS FC424 is 30 minutes, longer than that of the BRS Estilo cultivar and shorter than that of the BRS FC414 and Pérola cultivars. In relation to protein percentage in the beans, BRS FC424 (24%) was similar to BRS FC414 and Pérola and had a higher percentage than BRS Estilo. Moreover, BRS FC424 had an iron concentration (62 mg.kg^{-1}) in the grain higher than that of the BRS Estilo cultivar and similar to that of the Pérola and BRS FC414 cultivars. The zinc concentration (39 mg.kg^{-1}) was similar to that of the BRS FC414 cultivar and higher than that of the BRS Estilo and Pérola cultivars.

Table 2. Grain traits of the cultivar BRS FC424 compared to those of the check cultivars BRS FC414, Pérola, and BRS Estilo.

Cultivar	CT (minutes)	PC (%)	CFe (mg kg^{1})	CZn (mg kg^{1})	SY (%)	100SW (g)	COLOR	DARK
BRS FC424	30 b	23.6 a	62.3 a	38.8 a	85.1 a	24.8 c	Very light beige	Normal
BRS FC414	32 b	24.7 a	61.9 a	37.1 a	83.9 a	27.4 a	Very light beige	Normal
BRS Estilo	26 a	22.2 b	54.6 b	33.8 b	82.1 b	24.9 c	Very light beige	Normal
Pérola	32 b	24.0 a	61.6 a	34.0 b	79.9 c	26.2 b	Light beige	Normal

CT – cooking time; CP – protein concentration; CFe – iron concentration; CZn – zinc concentration; SY – sieve yield (sieve 12 - 4.5 mm); 100SW – 100-seed weight; COLOR – bean color; DARK – manner of seed darkening. Mean values followed by the same letter in the rows do not differ statistically from each other according to the Scott-Knott test at 5% probability.

Other traits

BRS FC424 has a normal cycle (from 85 to 94 days from emergence to physiological maturity), similar to that of the check cultivars. The plants are bush-type, with an indeterminate type II growth habit. Regarding plant architecture, BRS FC424 is an upright plant and has moderate resistance to lodging; it is adapted to mechanical harvest, including direct harvest. The flowers are white, and at physiological maturity and harvest, the pods are yellowish.

In field experiments, BRS FC424 showed resistance to bean common mosaic virus, moderate resistance to rust and angular leaf spot, and intermediate resistance to Fusarium wilt, root rots, and anthracnose. However, it proved to be susceptible to bean golden mosaic virus, bacterial wilt, and common bacterial blight. In general, BRS FC424 showed a similar level of resistance to the same diseases as BRS FC414, with superiority in relation to angular leaf spot. Yet, in relation to Pérola and BRS Estilo, BRS FC424 showed a higher level of resistance to diseases in general (Table 3).

Table 3. Agronomic traits and reaction to diseases of the cultivar BRS FC424 compared to those of the check cultivars BRS FC414, BRS Estilo, and Pérola.

Cultivar	Cycle	ARCH	LOD	AN	CBB	RU	AL	BCMV	BGMV	FOP	BW	RR
BRS FC424	N	Upright	MR	I	S	MR	MR	R	S	I	S	I
BRS FC414	N	Upright	MR	I	S	MR	S	R	S	I	S	I
BRS Estilo	N	Upright	MR	I	S	MR	S	R	S	S	S	S
Pérola	N	Semi-prostrate	I	S	S	MR	I	R	S	I	S	I

ARCH – plant architecture; LOD – lodging; AN – anthracnose; CBB – common bacterial blight; RU – rust; AL – angular leaf spot; BCMV – bean common mosaic virus; BGMV– bean golden mosaic virus; FOP – Fusarium wilt; BW – bacterial wilt; RR – root rots; N – normal cycle; R – resistant; MR – moderately resistant; I – intermediate; S – susceptible

Seed production

BRS FC424 was registered on 12 Sep. 2023 under number 54285, and protected in 22/10/2024, under number 20250062 in Brazilian Ministry of Agriculture (Ministério da Agricultura, Pecuária e Abastecimento – MAPA). Production of seeds with the same genetics is under the responsibility of Embrapa, and production to meet demand from bean producers will be undertaken 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), which signed the public-private partnership contract for development of new common bean cultivars with specific adaptation to certain regions, biomes, sowing seasons, climate conditions, or production systems.

Conclusion

The outstanding traits of BRS FC424 are high yield, especially in the Central-South Region of Brazil (Region I), and the excellent commercial quality of the grain (color, uniformity, 100-seed weight, and sieve yield). In addition, BRS FC424 has intermediate resistance to several diseases (root rots, Fusarium wilt, and anthracnose) and excellent levels of resistance to angular leaf spot.

Based on its performance, BRS FC424 was registered for the rainy and dry crop seasons in Region I (Mato Grosso do Sul, Paraná, Santa Catarina, São Paulo, and Rio Grande do Sul), for the rainy, dry, and winter crop seasons in Region II (Minas Gerais, Goiás, Distrito Federal, Mato Grosso, Tocantins, Maranhão, Bahia, Espírito Santo, and Rio de Janeiro), and for the rainy crop season in Region III (Sergipe, Alagoas,

Pernambuco, Rio Grande do Norte, Piauí, Ceará, and Paraíba).

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