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BRS FC422: Common bean cultivar with large *carioca* bean grain and resistance to diseases

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Abstract: BRS FC422 is a common bean cultivar with large *carioca* bean grain of very light beige seed coat color and 100-seed weight of 27 g. It has wide adaptation to different production regions; high mean yield (2,459 kg ha^{-1}), with greater superiority to check cultivars in Brazil's Central region (2,399 kg ha^{-1}) and higher yield in the South region (2,905 kg ha^{-1}); and high yield potential (4,347 kg ha^{-1}). BRS FC422 is classified as having moderate resistant to Fusarium wilt and anthracnose and intermediate resistance to common bacterial blight.

Keywords: Phaseolus vulgaris, 100-seed weight, plant breeding.

Introduction

Brazil is one of the largest producers and consumers of common bean (dry edible bean) worldwide (FAO, 2022). It constitutes a traditional food present in the diet of Brazilians and is consumed by all social classes; for those of lower purchasing power, it is the main source of proteins, minerals, vitamins, and fiber. Given the great importance of the crop, common bean breeding programs have been conducted in Brazil by research institutions that have been able to supply the market with new cultivars combining desirable characteristics, such as disease resistance, early maturity, better plant architecture, and greater yield potential (Pereira et al., 2021). Over a period of 26 years, these programs have led to an increase in crop yield from 737 kg ha^{-1} in 1994 to 1,498 kg ha^{-1} in 2020 (FEIJÃO, 2023). Although continuous gains have been obtained by breeding programs in Brazil, as the yield level of the cultivars increases, it is more difficult to identify superior genotypes for this trait, since the differences detected are smaller and smaller. Thus, other traits should be used for selection in breeding programs and in the final trials, aiming at increasing the probability of adding value to new cultivars that have similar yield. The Brazilian market has become more and more demanding in relation to traits related to the commercial quality of *carioca* (beige colored seed coat with brown streaks) bean grain, such as sieve yield, 100-seed weight, and seed coat color.

Other important demands of the production sector are incorporation of resistance to the main diseases in new cultivars. Among the most important leaf diseases in the bean crop, anthracnose is the most widespread in Brazil, occurring practically throughout the entire country. Fusarium wilt is also a very important disease, especially in the winter season with use of irrigation in the Central region of Brazil, which creates environmental conditions favorable to the occurrence of the disease. As there is no efficient chemical control for this disease, losses can even make use of the area unviable. Thus, the most efficient form of control is the use of resistant cultivars in an adequate production system, with use of crop rotation, no-till planting, biological products, cover crops, and other strategies that ensure the sustainability of production.

In recent years, some carioca common bean cultivars with very light beige seed coat color and normal darkening over time have been made available by Embrapa, such as BRS Estilo (Melo et al., 2010), which has high sieve yield and 100-seed weight, and intermediate resistance to anthracnose; BRS Sublime (Wendland et al., 2018), 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. However, none of them has a high level of resistance to Fusarium wilt.

BRS FC422 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 lines with specific adaptation to a determined region, biome, sowing season, climate condition, or production system that can be easily and successfully exploited by different sowers of common bean in their different regions of activity. The partners involved will have the mission of developing the market for these cultivars through research and seed production activities, as well as through promotional and marketing activities toward adoption of these cultivars by the production chain.

In this respect, BRS FC422 is a new cultivar, which stands out for high mean yield, especially in the Central and South regions of Brazil, and the excellent commercial quality of its grain (100-seed weight, seed coat color, and uniformity). In addition, BRS FC422 has moderate resistance to anthracnose and Fusarium wilt, which means it can be used in areas of intensive growing under center pivot irrigation.

Breeding Methods Used

CNFC 16567 arose from a cross between the line CNFC 8063 and the cultivar BRSMG Majestoso, made at Embrapa Arroz e Feijão in Santo Antônio de Goiás (GO, Brazil) in 2006. Also in 2006, the F_1 generation of the population was sown in a screened area. In 2007, 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 grain color, size, and yield. In the 2007 rainy season, the population in the F_3 generation was sown in Ponta Grossa (PR, Brazil) and harvested in bulk, with selection based on reaction to diseases (anthracnose, rust, and common bacterial blight); plant architecture; lodging; and grain color, size, and yield. In 2008, in the rainy season in Ponta Grossa, the F_4 generation was evaluated and harvested in bulk, with selection based on reaction to diseases (anthracnose, rust, and common bacterial blight); plant architecture; lodging; and grain color, size, and yield. In the 2009 winter season in Santo Antônio de Goiás, the F_5 generation was evaluated and individual

plants were selected to obtain lines based on plant architecture; lodging; and grain color, size, and yield.

In the 2010 dry season, in Ponta Grossa, the lines in the $F_{5:6}$ generation were sown in individual rows, and selection was made based on reaction to diseases (anthracnose, angular leaf spot, and bacterial wilt); plant architecture; lodging; and grain color, size, and yield. In the 2010 rainy season, the lines in the $F_{5:7}$ generation were sown in Ponta Grossa in individual rows, and selection was made based on reaction to diseases (anthracnose, rust, and common bacterial blight); plant architecture; lodging; and grain color, size, and yield. In the 2011 winter season in Santo Antônio de Goiás, the lines in the $F_{5:8}$ generation were evaluated and selected for plant architecture; lodging; and grain color, size, and yield. A line was selected, which received the name CNFC 16567. From this step on, the step of evaluation in experiments with replications in multiple environments began.

In 2012, the line CNFC 16567 was evaluated in the progeny test experiment, composed of 196 treatments – 192 new lines and 4 check cultivars (BRS Estilo, BRS Notável, Pérola, and IPR Tangará). A randomized block design was used with three replications and plots of two 4-m rows. The experiments were set up in three environments: Ponta Grossa, in the dry and rainy crop seasons; and Santo Antônio de Goiás, in the winter crop season. In these experiments, it was possible to evaluate grain yield, 100-seed weight, cycle, plant architecture, resistance to lodging, and reaction to diseases (anthracnose, angular leaf spot, common bacterial blight, and bacterial wilt). Combined analysis of these data led to selection of the line CNFC 16567 for participation in the preliminary experiment.

In 2013, the line CNFC 16567 was evaluated in the preliminary carioca experiment, composed of 81 treatments – 78 new lines and 3 check cultivars (BRS Estilo, Pérola, and BRS Notável). A randomized block design was used with three replications and plots of two or three 3-m rows. The experiments were conducted in five environments: Santo Antônio de Goiás (GO, Brazil) (two experiments), Brasília (DF, Brazil), and Sete Lagoas (MG, Brazil) in the winter crop season; and Ponta Grossa (PR, Brazil) in the rainy crop season. In these experiments, it was possible to evaluate the grain traits of yield, yield of sieve size 12 (4.5 mm), color, shape, uniformity, concentrations of iron, zinc, crude fiber, and protein, cooking time, and 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). Combined analysis of the data obtained in the preliminary experiment, together with the data obtained in the progeny test experiment, led to selection of the line CNFC 16567 for participation in the intermediate experiment, based on results of eight environments.

In 2016, the line CNFC 16567 was evaluated in the intermediate carioca experiment composed of 52 treatments – 45 new lines and 7 check cultivars (BRS FC402, BRS Estilo, BRS Notável, BRSMG Madrepérola, Pérola, ANFC09, and IPR Bem-te-vi). A randomized block design was used, with three replications and plots of two or three 3-m rows. The experiments were conducted in eleven environments: Santo Antônio de Goiás (GO, Brazil) (two experiments), Anápolis (GO, Brazil), Lavras (MG, Brazil), Uberlândia (MG, Brazil), and Sete Lagoas (MG, Brazil), in the winter crop season; Ponta Grossa (PR, Brazil), in the rainy and dry seasons; Paripiranga (BA, Brazil), in the rainy season; and Brasília (DF, Brazil), in the winter and rainy seasons. In these experiments, it was possible to evaluate grain yield, yield of sieve size 12 (4.5 mm), color, shape, uniformity, and 100-seed weight. In addition, evaluation was made of 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 of the progeny test, preliminary, and intermediate experiments led to selection of the line CNFC 16567 for the Value for Cultivation and Use Experiment (Experimento de Valor de Cultivo e Uso – VCU) based on evaluation of 19 environments. In 2017, in the winter season in Santo Antônio de Goiás, seeds were multiplied to have enough seeds for preparation of the VCU experiments.

In 2018 and 2019, the line CNFC 16567 was evaluated in 66 experiments composed of 22 treatments – 15 new lines with normal cycle and 6 check cultivars (BRS FC402, BRS Estilo, Pérola, BRSMG Uai, IPR Campos Gerais, and ANFC09). A randomized block design was used with three replications and plots 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, yield of sieve size 12 (4.5 mm), 100-seed weight, color, darkening, cooking time, and concentration of iron, zinc, and protein. The following traits were also evaluated through a scoring scale ranging from 1 (totally favorable phenotype) to 9 (totally unfavorable phenotype) (Melo, 2009): 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*), 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. The sieve yield was measured in the following manner: a 300 g sample was removed from each plot; the sample was then placed 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 100-seed weight. A Mattson cooker was used for determination of cooking time. Analyses of protein concentration were performed, determining nitrogen content by the micro-Kjeldahl method. Analyses of iron and zinc concentration were carried out by acid digestion of organic matter, according to the flame atomic absorption spectrophotometry technique.

Of the 66 experiments set up, 59 were harvested and achieved the experimental quality standards necessary to be considered in the cultivar registration process in relation to yield data. These 59 VCU experiments 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 and Minas Gerais) in the rainy, dry, and winter seasons, and in Region III (Pernambuco, Sergipe and Alagoas) in the rainy season.

Grain yield and yield potential

In these experiments, the cultivar BRS FC422 (CNFC 16567) exhibited mean yield of 2,459 kg ha^{-1}, similar to that of the cultivar Pérola (2,428 kg ha^{-1}) and higher than that of BRS Estilo (2,292 kg ha^{-1}) (Table 1). This also occurred in Region I (Center South). In Region II (Central), BRS FC422 exhibited higher mean yield (2,439 kg ha^{-1}) than the two check cultivars – 1.7% higher than Pérola, the highest yielding check cultivar. In Region III (Northeast), BRS FC422 had yield similar to that of Pérola, and both produced 11% less than BRS Estilo (1,306 kg ha^{-1}).

The yield potential of BRS FC422, obtained from the mean of the five experiments in which the cultivar had the highest yields, was 4,347 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, high yields can be achieved.

Table 1. Grain yield (kg ha^{-1}) of cv. BRS FC422 compared to the mean of two check cultivars (Pérola and BRS Estilo) in the Value for Cultivation and Use (VCU) trials, according to the recommended growing region and sowing time, from 2018 to 2019.

Region	Season	BRS FC422	Pérola	BRS Estilo	Number of environments
I	Rainy	3,346 a	3,299 a	3,201 b	15
	Dry	2,169 a	2,166 a	2,014 b	8
	Overall	2,936 a	2,905 a	2,788 b	23
II	Rainy	2,429 a	2,367 a	2,126 b	11
	Dry	1,879 a	1,714 b	1,591 c	3
	Winter	2,566 a	2,570 a	2,319 b	14
	Overall	2,439 a	2,399 b	2,165 c	28
III	Rainy	1,159 b	1,159 b	1,306 a	8
Overall	**-**	**2,459 a**	**2,428 a**	**2,292 b**	**59**

Region I – SC, PR, MS, SP; Region II – MG, GO, DF, MT; Region III – SE, AL, 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 technological and industrial quality traits of the grain, the cultivar BRS FC422 has good sieve 12 (4.5 mm) yield (71%), lower than that of the cultivars BRS Estilo and Pérola and higher than that of BRS FC402 (Table 2). BRS FC422 has mean 100-seed weight of 27 grams higher all cultivars. The grain is carioca type (cream colored with brown streaks), of elliptical shape, and without shine. In relation to appearance of the grain, BRS FC422 proved to be similar to BRS Estilo, with grain of a very light cream color, light brown streaks, and normal grain darkening. Pérola and BRS Estilo are cultivars of reference in the market in relation to commercial grain quality. Mean cooking time of BRS FC422 is 32 minutes, higher than that of the cultivar BRS Estilo, similar of the cultivar Pérola and lower BRS FC402. In relation to grain protein percentage, BRS FC422 (20%) was similar to that of BRS FC402 and higher than that of the cultivars Pérola and BRS Estilo. Furthermore, BRS FC422 had iron concentration (56 mg kg^{-1}) in the grain higher than that of the cultivar BRS Estilo and lower than that of the cultivars Pérola and BRS FC402. Zinc concentration (34 mg kg^{-1}) was similar to that of BRS Estilo and Pérola and lower than that of BRS FC402.

Table 2. Grain traits of the common bean cultivar BRS FC422 compared to those of the check cultivars Pérola, BRS FC402, and BRS Estilo.

Cultivar	CT (minutes)	PC (%)	FeC (mg kg^{-1})	ZnC (mg kg^{-1})	RP (%)	W100 (g)	COLOR	DARK
BRS FC422	32 b	20 a	56 c	34 b	71 b	27 a	very light beige	normal
BRS Estilo	26 a	17 b	51 d	35 b	78 a	25 c	very light beige	normal
BRS FC402	36 c	20 a	67 a	38 a	66 c	24 d	light beige	normal
Pérola	33 b	18 b	61 b	35 b	80 a	26 b	light beige	normal

CT – cooking time, PC – protein content, FeC – iron content, ZnC – zinc content, RP – sieved grain yield (< 4.5 mm), W100 – 100-seed weight, COLOR – predominant color, DARK – seed coat 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 FC422 proved to have resistance to the bean common mosaic virus and to rust, moderate resistance to Fusarium wilt and anthracnose, and intermediate resistance to common bacterial blight. However, it proved to be susceptible to the bean golden mosaic virus, bacterial wilt, and angular leaf spot. In general, BRS FC422 had the same level of resistance to the same dis-

eases as BRS FC402, which is one of the cultivars with better performance for diseases.

BRS FC422 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-like, with an indeterminate type III growth habit. In relation to plant architecture, BRS FC422 is semi-upright and has intermediate resistance to lodging; it is adapted to mechanical harvest, including direct harvest. Its flowers are white, and at physiological maturity and at harvest, the pods are yellowish.

Table 3. Agronomic traits and disease reaction traits of the cultivar BRS FC422 compared to those of the carioca grain cultivars BRS Estilo, BRS FC402, and Pérola.

Cultivar	Cycle	ARCH	LOD	AN	CBB	RU	ALS	BCMV	BGMV	FW	CUR
BRS FC422	N	semi-upright	I	MR	I	R	S	R	S	MR	S
BRS Estilo	N	upright	MR	I	S	R	S	R	S	S	S
BRS FC402	N	semi-prostrate	I	MR	I	R	S	R	S	MR	S
Pérola	N	semi-prostrate	I	S	S	R	I	R	S	I	S

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, N – normal cycle, R – resistant, MR – moderately resistant, I – intermediate, S – susceptible.

Seed production

BRS FC422 was registered in 2022 under number 50590 with the Brazilian Ministry of Agriculture (Ministério da Agricultura, Pecuária e Abastecimento – MAPA). Seed production will be under the responsibility of Embrapa, and production to meet the needs of grain producers will be carried out exclusively by the 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) that were signatories in a public-private partnership contract for development of new common bean cultivars.

Conclusions

Prominent traits for BRS FC422 are high yield in the Central Region (Region II) and the excellent commercial quality of its grain. It also stands out through joining resistance to various diseases, with excellent levels of resistance to anthracnose and to Fusarium wilt, and an intermediate level of resistance to common bacterial blight, in a way similar to BRS FC402, which is a standard of resistance to diseases among the carioca bean cultivars. For the diseases cited, except for anthracnose, the chemical control available is not yet effective.

Based on its performance, BRS FC422 will be 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 (Goiás, Distrito Federal, Minas Gerais, 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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