FUNCTIONAL PLANT BREEDING JOURNAL
Scientific Journal. ISSN 2595-9433
Volume 6, Article n. 03, Jan/December
D.O.I. http://dx.doi.org/10.35418/2526-4117/v6a03
Received: 11/14/2023 - Accepted: 02/28/2024

'BRS FC416': carioca common bean cultivar with high commercial quality of grain and resistance to Fusarium wilt, anthracnose, and common bacterial blight

Helton Santos Pereira[1*], Thiago Lívio Pessoa Oliveira de Souza[1], Marcelo Sfeir Aguiar[1], Luís Cláudio de Faria[1], Joaquim Geraldo Cáprio da Costa[1], Paula Pereira Torga[1], Saulo Muniz Martins[1], Cléber Morais Guimarães[1], Válter Martins de Almeida[2], Leonardo Cunha Melo[1]

[1] *Embrapa Arroz e Feijão, Rod. GO-462, km 12, Santo Antônio de Goiás, GO, Brazil;*
[2] *Empresa Mato-Grossense de Pesquisa, Assistência e Extensão Rural (Empaer–MT), Rua Carlos Avalone, s/n, Centro Político Administrativo, Cuiabá, MT, Brazil.*
** Corresponding author: helton.pereira@embrapa.br*

Abstract: 'BRS FC416' is a common bean cultivar with carioca bean grain of very light beige seed coat color, high sieve yield, and high 100-seed weight. It exhibits wide adaptation to different production regions and high mean yield (2,529 kg ha^{-1}), especially for the Central (2,541 kg ha^{-1}) and Northeast (1,423 kg ha^{-1}) regions, and high yield potential (4,219 kg ha^{-1}). 'BRS FC416' also has high resistance to Fusarium wilt and intermediate resistance to anthracnose and to common bacterial blight.

Keywords: *Phaseolus vulgaris*, sieve yield, 100-seed weight

Introduction

In recent years, Brazil has been among the largest worldwide producers (2.3 million metric tons and 1.5 million hectares planted area annually) and consumers of common bean (*Phaseolus vulgaris*) (EMBRAPA, 2023) (FAO, 2022), and the carioca commercial group (beige with brown streaks) represents around 70% of the Brazilian consumer market (Pereira et al., 2021a).

The Brazilian market has become more and more demanding in relation to traits related to the commercial quality of the carioca grain, such as sieve yield, 100-seed weight, and grain color. The 'Pérola' cultivar was considered the standard for grain commercial quality for nearly 20 years (from 1995 to 2014), by exhibiting high sieve yield, high uniformity, and high 100-seed weight, as well as the light beige color of the seed coat. However, release of the 'BRS Estilo' cultivar (Melo et al., 2010) modified the commercial standard in relation to seed coat color, because the very light beige color of 'BRS Estilo' came to be preferred. Thus, the market came to value new carioca common bean cultivars with very light beige seed coat color. There are currently market segments for cultivars with grain that has slow darkening or for cultivars with grain that has normal darkening.

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 crop, anthracnose, caused by the fungus *Coletotrichum lindemu-*

tianum, is most widespread in Brazil, occurring practically throughout the country. Another important leaf disease is common bacterial blight, caused by the bacterium *Xanthomonas axonopodis* pv. *phaseoli*, for which chemical control is not yet very effective. Fusarium wilt is a disease caused by the fungus *Fusarium oxysporum* f. sp. *Phaseoli,* which is quite important in the Central region of Brazil in the winter crop season using center pivot irrigation. Winter crop season use high technology and combine environmental conditions favorable to occurrence of the disease. In this situation, there is intensive use of areas for growing common bean, and as the pathogen inhabits the soil and there is no effective chemical control, losses from the disease can even make use of the area unviable. Therefore, the most effective form of control is the use of resistant cultivars in an integrated management system.

In recent years, some carioca common bean cultivars with very light beige grain color and normal darkening have been made available by Embrapa, such as 'BRS Estilo' (Melo et al., 2010), which exhibits 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 to 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 show a high level of resistance to Fusarium wilt.

In that respect, 'BRS FC416' is a new cultivar that stands out for its high mean yield, especially for the Central and Northeast regions of Brazil, and the excellent commercial quality of its grain (sieve yield, 100-seed weight, color, and uniformity). In addition, 'BRS FC416' has moderate resistance to Fusarium wilt, which allows it to be used in areas of intensive growing under center pivot irrigation, and intermediate resistance to anthracnose and common bacterial blight.

Breeding Methods Used

'CNFC 16564' originated from a cross between the line 'CNFC 8063' and the cultivar 'BRSMG Majestoso' carried out at Embrapa Arroz e Feijão in Santo Antônio de Goiás (GO) in 2006. Also in 2006, the F_1 generation of the population was sown in a screened enclosure. In 2007, in the winter crop 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, resistance to lodging, and grain color, size, and yield. In the 2007 rainy crop season, the population in the F_3 generation was sown in Ponta Grossa (PR) and harvested in bulk, with selection based on reaction to diseases (anthracnose, rust, and common bacterial blight), plant architecture, resistance to lodging, and grain color, size, and yield. In 2008, in the rainy crop season in Ponta Grossa, the F_4 generation was evaluated and harvested in bulk, with selection based on reaction to diseases (anthracnose, rust, common bacterial blight), plant architecture, resistance to lodging, and grain color, size, and yield. In the 2009 winter crop season in Santo Antônio de Goiás, the F_5 generation was evaluated, and individual plants were selected to obtain lines based on plant architecture, resistance to lodging, and grain color, size, and yield.

In 2010, in the dry crop 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, resistance to lodging, and grain color, size, and yield. In 2010, in the rainy crop 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, resistance to lodging, and grain color, size, and yield. In 2011, in the winter crop season in Santo Antônio de Goiás, the lines of the $F_{5:8}$ generation were evaluated and selected for plant architecture, resistance to lodging, and grain color, size, and yield, selecting the line that received the name CNFC 16564. As of that point, the step began of evaluation

in experiments with replications in multiple environments.

In 2012, the 'CNFC 16564' line was evaluated in the carioca progeny test experiment composed of 196 treatments: 192 new lines and four check cultivars ('BRS Estilo', 'BRS Notável', 'Pérola', and 'IPR Tangará'). The experimental design used was randomized blocks 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). Joint analysis of these data led to selection of the line 'CNFC 16564' for participation in the preliminary carioca experiment.

In 2013, the 'CNFC 16564' line was evaluated in the preliminary carioca experiment, composed of 81 treatments: 78 new lines and three 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) (two experiments), Brasília (DF), and Sete Lagoas (MG) in the winter crop season; and Ponta Grossa (PR) in the rainy crop season. In these experiments, it was possible to evaluate yield, no. 12 sieve (4.5 mm) yield, color, 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 obtained in the preliminary carioca experiment, together with the data obtained in the carioca progeny test experiment, led to selection of the 'CNFC 16564' line to participate in the intermediate carioca experiment, based on results from eight environments.

In 2016, the 'CNFC 16564' line 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) (two experiments), Anápolis (GO), Lavras (MG), Uberlândia (MG), and Sete Lagoas (MG) in the winter crop season; Ponta Grossa (PR) in the rainy and dry crop seasons; Paripiranga (BA) in the rainy crop season; and Brasília (DF) in the winter and rainy crop seasons. In these experiments, it was possible to evaluate yield, no. 12 (4.5 mm) sieve yield, color, shape, uniformity, and 100-seed weight. In addition, cycle, plant architecture, resistance to lodging, and reaction to diseases (anthracnose, angular leaf spot, common bacterial blight, bacterial wilt, and Fusarium wilt) were evaluated.

Joint analysis of the data of the progeny and preliminary and intermediate carioca test experiments led to selection of the 'CNFC 16564' line for the Value for Cultivation and Use (VCU) experiment, based on evaluation of 19 environments. In 2017, in the winter crop season in Santo Antônio de Goiás, seeds were multiplied to obtain enough to prepare the VCU experiments.

In 2018 and 2019, the 'CNFC 16564' line was evaluated in 66 experiments composed of 22 treatments: 16 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, no. 12 sieve (4.5 mm) yield, 100-seed weight, color, darkening, uniformity, cooking time, and concentration of iron, zinc, and protein. In addition, a scale with scores ranging from 1 (totally favorable phenotype) to 9 (totally unfavorable phenotype) 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*), bean common mosaic virus (BCMV), and bean golden mosaic virus (BGMV).

Grain yield was measured in kg ha^{-1} and corrected for 13% grain moisture. Sieve yield was measured as follows: a 300-g sample was taken from each plot; this sample was passed through a sieve with oblong openings of 4.5 mm thickness; 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. A new sample of 100 seeds was taken from the seeds retained in the sieve and weighed to obtain the 100-seed weight. A Mattson cooker was used for determination of cooking time. Protein concentration was analyzed, determining the nitrogen content by the micro-Kjeldahl method (AOAC, 2005). Iron and zinc concentrations were analyzed 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 standards of experimental quality 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 crop seasons, in Region II (Goiás, Distrito Federal, Mato Grosso, and Minas Gerais) in the rainy, dry, and winter crop seasons, and in Region III (Pernambuco, Sergipe, and Alagoas) in the rainy crop season.

Grain yield and yield potential

In these experiments, the cultivar 'BRS FC416' ('CNFC 16564') had high mean yield (2,529 kg ha^{-1}), 4.2% higher than that of the 'Pérola' cultivar (2,428 kg ha^{-1}) and 10.3% higher than that of 'BRS Estilo' (2,067 kg ha^{-1}) (Table 1). This also occurred in Region II (Central), with 5.9% and 17.4% higher yields compared to 'Pérola' and 'BRS Estilo', respectively. In Region III (Northeast), 'BRS FC416' had 22.8% higher yield than 'Pérola' and 9% higher yield compared to 'BRS Estilo'. In Region I (Center-South), 'BRS FC416' had mean yield (2,900 kg ha^{-1}) similar to that of the 'Pérola' cultivar (2,905 kg ha^{-1}), and 4% higher than that of 'BRS Estilo' (2,788 kg ha^{1}).

The yield potential of 'BRS FC416', obtained from the mean of the five experiments in which this cultivar had the highest yields, was 4,219 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 FC416' compared to the mean of two check cultivars ('BRS Estilo' and 'Pérola') 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 FC416'	'Pérola'	'BRS Estilo'	Number of environments
I	Rainy	3,235 a	3,299 a	3,201 a	15
	Dry	2,273 a	2,166 a	2,014 b	8
	Overall	2,900 a	2,905 a	2,788 b	23
II	Rainy	2,593 a	2,367 b	2,126 c	11
	Dry	2,052 a	1,714 b	1,591 b	3
	Winter	2,604 a	2,570 a	2,319 b	14
	Overall	2,541 a	2,399 b	2,165 c	28
III	Rainy	1,423 a	1,159 c	1,306 b	8
Overall	-	2,529 a	2,428 b	2,292 c	59

Region I - SC, PR, MS and SP; Region II – MG, ES, GO, DF, MT; Region III – SE, AL, 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.

Commercial and nutritional seed quality

In relation to the traits of grain technological and industrial quality, the cultivar 'BRS FC416' has good sieve yield (76%), slightly lower than that of the cultivars 'BRS Estilo' and 'Pérola' (Table 2). 'BRS FC416' has a mean 100-seed weight of 28 grams, higher than that of the cultivars 'BRS Estilo' and 'Pérola', which are references in the market in relation to grain commercial quality. The grain is carioca type, elliptical, uniform, and not shiny. In relation to grain appearance, 'BRS FC416' is similar to 'BRS Estilo', with grain that has uniform color, very light beige, light brown streaks, and normal grain darkening. Mean cooking time of 'BRS FC416' is 35 minutes, longer than that of the cultivars 'Pérola' and 'BRS Estilo' and similar to that of 'BRS FC402'. In relation to protein percentage in the grain, 'BRS FC416' (18%) is similar to the cultivars 'Pérola' and 'BRS Estilo', and higher than 'BRS FC402'. Furthermore, 'BRS FC416' has iron concentration (53 mg kg^{-1}) in the grain similar to that of the cultivar 'BRS Estilo' and lower than that of the 'Pérola' and 'BRS FC402' cultivars. Zinc concentration (31 mg kg^{-1}) is lower than that of the three check cultivars.

Table 2. Comparison of grain traits of the carioca common bean cultivar 'BRS FC416' with the check cultivars 'Pérola', 'BRS FC402', and 'BRS Estilo'.

Cultivar	CT (minutes)	PC (%)	FeC (mg kg^{-1})	ZnC (mg kg^{-1})	SY (%)	W100 (g)	Color	Color Uniformity	Dark
'BRS FC416'	36 c	18 b	53 c	31 c	76 b	28 a	very light beige	high	normal
'BRS Estilo'	26 a	17 b	51 c	35 b	78 a	25 c	very light beige	high	normal
'BRS FC402'	36 c	20 a	67 a	38 a	66 c	24 d	light beige	high	normal
'Pérola'	33 b	18 b	61 b	35 b	80 a	27 b	light beige	high	normal

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

Table 3. Agronomic traits and disease reaction traits of the cultivar 'BRS FC416' in comparison with the carioca grain check cultivars 'BRS Estilo', 'BRS FC402', and 'Pérola'.

Cultivar	Cycle	ARCH	LOD	AN	CBB	RU	ALS	BCMV	BGMV	FW	BW
'BRS FC416'	N	semi-upright	I	I	I	MR	S	R	S	MR	S
'BRS Estilo'	N	upright	MR	I	S	MR	S	R	S	S	S
'BRS FC402'	N	semi-prostrate	I	MR	I	MR	S	R	S	MR	S
'Pérola'	N	semi-prostrate	I	S	S	MR	I	R	S	I	S

ARCH – plant architecture; LOD – lodging resistance; 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; BW – bacterial wilt; N – normal cycle; R – resistant; MR – moderately resistant; I – intermediate; S - susceptible

Other Traits

In the field experiments, 'BRS FC416' showed resistance to bean common mosaic virus, moderate resistance to rust and Fusarium wilt, and intermediate resistance to anthracnose and common bacterial blight. However, it showed susceptibility to bean golden mosaic virus, bacterial wilt, and angular leaf spot.

'BRS FC416' 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 an indeterminate type II/III growth habit. In relation to plant architecture, 'BRS FC416' is semi-upright and has intermediate resistance to lodging, and it is adapted to mechanical harvest, including direct harvest. The flowers are white, and at physiological maturity and harvest, the pods are yellowish.

Seed production

'BRS FC416' was registered in 2023, under number 51170, and the documents for the protection request have already been

sent to the Brazilian Ministry of Agriculture (Ministério da Agricultura, Pecuária e Abastecimento – MAPA). Genetic seed production will be under the responsibility of Embrapa, and production to meet the needs of common bean growers will be carried out by seed production companies that will be selected through a public call notice.

Conclusions

'BRS FC416' stands out for its high mean yield, especially for the Central and Northeast regions, and excellent grain commercial quality (sieve yield, 100-seed weight, color, and uniformity). In addition, it has moderate resistance to Fusarium wilt, which allows it to be used in intensive growing areas under center pivot irrigation, and intermediate resistance to anthracnose and common bacterial blight.

Based on its performance, 'BRS FC416' 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).

Acknowledgments

To the other units of Embrapa and to the partner institutions in cultivar evaluation, especially Embrapa Arroz e Feijão; Secretaria de Inovação e Negócios da Embrapa, Embrapa Tabuleiros Costeiros; Embrapa Agropecuária Oeste; Embrapa Milho e Sorgo; Embrapa Soja; Embrapa Cerrados; Embrapa Semi-árido; Empresa de Pesquisa Agropecuária e Extensão Rural de Mato Grosso; Emater Alagoas; Emater Goiás; Fundação de Ensino Superior de Rio Verde; Universidade Federal de Lavras; Universidade Federal de Uberlândia; Universidade Estadual de Montes Claros; and Universidade Estadual Paulista - Ilha Solteira.

References

Association of Official Analytical Chemist (2005). **Official methods of analysis (18nd ed.)**. AOAC International.

EMBRAPA. **Dados de conjuntura da produção de feijão comum (*Phaseolus vulgaris* L.) no Brasil: 1985 a 2021**. Available at: <http://www.cnpaf.embrapa.br/socioeconomia/index.htm>. Accessed on: Jan. 8, 2023.

FAO. **Faostat**. Available at: <http://faostat3.fao.org/browse/Q/QC/E>. Accessed on Jan. 16, 2023.

MELO, L.C. 2009. **Procedimentos para condução de ensaios de valor de cultivo e uso em feijoeiro-comum**. Santo Antônio de Goiás: Embrapa Arroz e Feijão. 104p. (Embrapa Arroz e Feijão. Documentos, 239).

MELO, L.C.; DEL PELOSO, M.J.; PEREIRA, H.S.; FARIA, L.C.; COSTA, J.G.C.; DÍAZ, J.L.C.; RAVA, C.A.; WENDLAND, A.; ABREU, A.F.B. 2010. BRS Estilo - Common bean cultivar with Carioca grain, upright growth and high yield potential. **Crop Breeding and Applied Biotechnology**, 10:377-379.

MELO, L.C.; PEREIRA, H.S.; SOUZA, T.L.P.O.; FARIA, L.C.; AGUIAR, M.S.; CARVALHO, H.W.L.; ALMEIDA, V.M.; COSTA, A.F.; ITO, M.A.; PEREIRA FILHO, I.A.; MAGALDI, M.C.S.; KNUPP, A.M.; COSTA, J.G.C.; SOUZA, N.P. 2022a. BRS FC310: carioca common bean cultivar with semi-early cycle, upright growth habit, and resistance to major diseases. **Functional Plant Breeding Journal,** 4, 23-28. http://dx.doi.org/10.35418/2526-4117/v4n1a3.

MELO, L.C.; SOUZA, T,L.P.O.; AGUIAR, M.S.; FARIA, L.C.; COSTA, J.G.C.; MAGALDI, M.C.S; SOUZA, N.P.; KNUPP, A.M.; TORGA, P.P.; CARVALHO, H.L.M.; ALMEIDA, V.M.; PEREIRA, H.S. 2022b. BRS FC414: Common bean cultivar with high yield and commercial quality, recommended for growing under center pivot irrigation. **Functional Plant Breeding Journal**, 4, 53-58. *http://dx.doi.org/10.35418/2526-4117/v4n2a6*.

PEREIRA, H.S.; DEL PELOSO, M.J.; SOUZA, T.L.P.O.; FARIA, L.C.; AGUIAR, M.S.; WENDLAND, A.; COSTA, J.G.C.; DÍAZ, J.L.C.; MAGALDI, M.C.S.; ABREU, A.F.B.; PEREIRA FILHO, I.A.; ALMEIDA, V.M.; MARTINS, M.; MELO, L.C. 2021. BRS FS305 - Common bean cultivar with calima bean for export. **Functional Plant Breeding Journal**, 3: 75-79. *http://dx.doi.org/10.35418/2526-4117/v3n1a8*

WENDLAND, A.; PEREIRA, H.S.; FARIA, L.C.; SOUZA, T.L.P.O.; DEL PELOSO, M.J.; COSTA, J.G.C.; DÍAZ, J.L.C.; MAGALDI, M.C.S.; ALMEIDA, V.M.; CARVALHO, H.W.L.; MELO, C.L.P.; COSTA, A.F.; ABREU, A.F.B.; MELO, L.C. 2018. BRS Sublime: Common bean cultivar with carioca grain, resistance to angular leaf spot and high nutritional quality. **Crop Breeding and Applied Biotechnology**, 18: 440-445