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BRS FP417: BLACK COMMON BEAN CULTIVAR WITH HIGH YIELD, HIGH COMMERCIAL-QUALITY GRAIN, AND DISEASE RESISTANCE

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Abstract: BRS FP417 is a common bean cultivar with black bean grain and high yield (2,465 kg ha^{-1}), excellent commercial-quality grain, upright plant architecture, and resistance to lodging. In addition, it has excellent levels of resistance to anthracnose and to Fusarium wilt and intermediate resistance to common bacterial blight and to bacterial wilt.

Keywords: *Phaseolus vulgaris*, anthracnose, common bacterial blight, fusarium wilt.

Introduction

Common bean (*Phaseolus vulgaris* L.) is one of the main foods that is a source of plant protein for direct human consumption. It is widely grown and consumed in most countries of Latin America and Africa in different regions and is sown in different growing seasons. In recent years, Brazil has been among the main producers and consumers of common bean worldwide, with 2.3 million metric tons produced on 1.5 million hectares annually (EMBRAPA, 2023; FAO, 2022).

Among the diverse commercial groups of common bean consumed in Brazil, the black group represents around 20% of the Brazilian consumer market, which corresponds to approximately 460,000 metric tons annually (Pereira et al., 2021). The greatest demand for black bean is in the states of Paraná, Santa Catarina, Rio Grande do Sul, Rio de Janeiro, and Espírito Santo.

In years in which domestic production is not able to supply the internal market, Brazil often imports black beans from other countries, such as Argentina and China. One of the solutions to reduce or end these imports is recommendation of new cultivars that contribute to increase the yield of common bean in Brazil. The Common Bean Breeding Program of Embrapa Arroz e Feijão focuses on developing cultivars with high yield potential, disease resistance, and upright plant architecture, with a view toward direct mechanized harvest so that farmers offer a product of better quality to consumers and,

consequently, achieve better income from the crop (Pereira et al., 2013).

In recent years, some black bean cultivars have already been made available by Embrapa, such as BRS Esteio, which is one of the black bean cultivars most planted at this time. It has high yield potential, high commercial-quality grain (100-seed weight, appearance, and sieve yield), and moderate resistance to anthracnose (Pereira et al., 2013). Recently, BRS FP403 was made available, which has high yield, excellent commercial quality grain, greater 100 seed weight in relation to BRS Esteio, and moderate resistance to Fusarium wilt and to root rots (*Fusarium solani* f. sp. *phaseoli* and *Rhizoctonia. solani)* (Souza et al., 2019).

Within this context, BRS FP417 is a new cultivar that stands out through combining resistance to various diseases, with excellent levels of resistance to anthracnose and to Fusarium wilt and intermediate resistance to common bacterial blight and to bacterial wilt. In addition, it has high yield, excellent commercial-quality grain, upright plant architecture, and resistance to lodging.

Breeding Methods Used

CNFP 16380 originated from the cross between the cultivars BRS Esplendor and BRS Campeiro made 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 under screened protection. In the 2007 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 appearance, size, and yield. In the 2007 rainy 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 appearance, 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, resistance to lodging, and grain appearance, 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, resistance to lodging, and grain appearance, 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, resistance to lodging, and grain appearance, 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, resistance to lodging, and grain appearance, 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, resistance to lodging, and grain appearance, size, and yield, selecting the line that received the name CNFP 16380. From this step on, the evaluation stage began in experiments with replications in multiple environments.

In 2012, the line CNFP 16380 was evaluated in the black bean progeny test experiment, composed of 100 treatments: 96 new lines and 4 check cultivars (BRS Esteio, BRS Esplendor, BRS Campeiro, and IPR Uirapuru). 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 seasons, and Santo Antônio de Goiás in the winter 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 CNFP 16380 for participation in the preliminary experiment.

In 2013, the line CNFP 16380 was evaluated in the black bean preliminary experiment, composed of 57 treatments: 53 new lines and 4 check cultivars (BRS Esteio, BRS Esplendor, BRS Campeiro, and IPR Uirapuru). A randomized block design was used with three replications and plots of two or three 3-m rows. The experiments were conducted in four environments: Santo Antônio de Goiás (GO) (two experiments) and Uberlândia (MG) in the winter season, and Ponta Grossa (PR) in the rainy season. In these experiments, it was possible to evaluate yield; yield of sieve size 11 (4.25 mm); grain color, shape, and uniformity; concentrations of iron, zinc, crude fiber, and protein, cooking time, and 100-seed weight of the beans; 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 CNFP 16380 for participation in the intermediate experiment, based on the results of eight environments.

In 2016, the line CNFP 16380 was evaluated in the black bean intermediate experiment, composed of 20 treatments: 15 new lines and 5 check cultivars (BRS Esteio, BRS FP403, BRS Esplendor, IPR Tuiuiu, and IPR Uirapuru). A randomized block design was used with three replications and plots of two or three 3-m rows. The experiments were conducted in nine environments: Santo Antônio de Goiás (GO), Anápolis (GO), Uberlândia (MG), and Sete Lagoas (MG) in the winter season; Ponta Grossa (PR) in the rainy and dry seasons; Paripiranga (BA) in the rainy season; and Brasília (DF) in the winter and rainy seasons. In these experiments, it was possible to evaluate yield; yield of sieve size 11 (4.25 mm); and grain 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.

Combined analysis of the data of the progeny test, preliminary, and intermediate black bean experiments led to selection of the line CNFP 16380 for the Value for Cultivation and Use (Valor de Cultivo e Uso - VCU) experiment, based on evaluation of 16 environments. In the 2017 winter season in Santo Antônio de Goiás, seeds were multiplied to obtain a sufficient number for preparation of the VCU experiments.

In 2018 and 2019, the line CNFC 16380 was evaluated in 67 experiments composed of 11 treatments of black beans: 7 new lines with normal cycle and 4 check cultivars (BRS FP403, BRS Esteio, IPR Tuiuiu, and IPR Uirapuru). 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 11 (4.25 mm), 100-seed weight, color, cooking time, and concentration of iron, zinc, and protein. The following traits were also evaluated using 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 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*), bean common mosaic virus (BCMV), bean golden mosaic virus (BGMV), and root rots.

Grain yield was measured in kg ha^{-1} and corrected to 13% grain moisture content. Sieve 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 4.25 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 in the sieve, 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 was carried out, determining the nitrogen content by the micro-Kjeldahl method. The 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 67 experiments set up, 60 achieved the standards of experimental quality necessary to be considered in the cultivar registration process in relation to yield data. The 60 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, Minas Gerais, and Rio de Janeiro) in the rainy, dry, and winter seasons; and in Region III (Sergipe and Alagoas) in the rainy season.

Grain yield and yield potential

The cultivar BRS FP417 (CNFP 16380) had mean yield of 2,465 kg ha^{-1}, 3.6% and 3.1% lower than that of the cultivars BRS FP403 (2,558 kg ha^{-1}) and BRS Esteio (2,543 kg ha^{-1}), respectively, and 3.0% greater than that of the control IPR Uirapuru (2,405 kg ha^{-1}) (Table 1). BRS Esteio, the black bean cultivar most planted at this time, and BRS FP403, the cultivar recommended most recently by Embrapa, stand out for their yields, which are significantly higher than those of other cultivars available on the market. In Region I (Central-South), which is the main black bean production region, BRS FP417 had mean yield (2,744 kg ha^{-1}) similar to that of the cultivar IPR Uirapuru (2,737 kg ha^{-1}), and was 8.3% and 3.9% lower than that of BRS FP403 (2,993 kg ha^{-1}) and of BRS Esteio (2,841 kg ha^{-1}), respectively. In Region II (Central), BRS FP417 had mean yield of 2,415 kg ha^{-1}, similar to that of the check cultivar with the highest yield (BRS Esteio), and was 1.0% higher than that of BRS FP403 and 4.8% higher than that of IPR Uirapuru. In Region III (Northeast), BRS FP417 had yield similar to that of the three check cultivars (Table 1).

The yield potential of BRS FP417, obtained from the mean of the five experiments in which this cultivar had the highest yields, was 4,096 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. Yield (kg ha^{-1}) of the cultivar BRS FP417 compared to the three check cultivars (BRS FP403, BRS Esteio, and IPR Uirapuru) in the Value for Cultivation and Use (VCU) experiments, according to the regions of recommendation of cultivars and sowing seasons in 2018 and 2019.

Region	Crop Season	BRS FP417	BRS Esteio	BRS FP403	IPR Uirapuru	Number of environments
I	Rainy	3,147 b	3,146 b	3,329 a	3,079 c	16
	Dry	1,823 b	2,142 a	2,225 a	1,955 b	7
	Mean	2,744 c	2,841 b	2,993 a	2,737 c	23
II	Rainy	2,704 a	2,583 a	2,682 a	2,476 b	9
	Dry	2,000 a	1,882 a	2,075 a	1,984 a	4
	Winter	2,386 b	2,549 a	2,373 b	2,310 b	18
	Mean	2,415 a	2,469 a	2,392 b	2,305 b	31
III	Rainy	1,583 a	1,763 a	1,586 a	1,512 a	6
Overall mean	**-**	**2,465 b**	**2,543 a**	**2,558 a**	**2,405 b**	**60**

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.

Commercial and industrial traits of the grain

In relation to technological and industrial quality traits of the grain, the cultivar BRS FP417 has high yield of sieve size 11 (4.25 mm) (86%), slightly lower than that of the

cultivar BRS Esteio (89%), similar to that of BRS FP403 (87%), and higher than that of IPR Uirapuru (84%) (Table 2).

BRS FP417 has mean 100-seed weight of 23 grams, similar to that of BRS Esteio (23 g) and lower than that of BRS FP403 (25 g), which are references in the market in relation to commercial quality of the grain. The beans are black with an elliptical semi-full degree of flatness, without shine. In relation to grain appearance, BRS FP417 had beans with uniform color and shape. Mean cooking time of BRS FP417 was 32 minutes, similar to that of the three check cultivars. In relation to percent of protein in the beans, BRS FP417 had grain protein percentage classified as intermediate (19%), which was higher than the percentages of the three check cultivars. BRS FP417 also had an intermediate iron concentration in the beans (65 mg kg^{-1}), which was similar to that of the cultivar BRS Esteio and slightly higher than the concentrations of the cultivars BRS FP403 and IPR Uirapuru. The zinc concentration (38 mg kg^{-1}) was also intermediate, and was similar to that of the three check cultivars.

Table 2. Grain traits of the cultivar BRS FP417 compared to the check cultivars BRS FP403, BRS Esteio, and IPR Uirapuru.

Cultivar	CT (minutes)	CP (%)	CFe (mg kg^{-1})	CZn (mg kg^{-1})	SY (%)	100SW (g)
BRS FP417	32 a	19 a	65 a	38 a	86 b	23 b
BRS FP403	31 a	17 b	63 b	38 a	87 b	25 a
BRS Esteio	33 a	18 b	65 a	38 a	89 a	23 b
IPR Uirapuru	32 a	18 b	64 b	36 a	84 c	22 c

CT – cooking time; CP – protein concentration; CFe – iron concentration; CZn – zinc concentration; SY – yield of sieve size 11 (4.25 mm); 100SW – 100-seed weight.
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 FP417 had 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 II growth habit. In relation to plant architecture, BRS FP417 is upright, like the three check cultivars. BRS FP417 was resistant to lodging, similar to BRS FP403 and superior to the other check cultivars. These traits make BRS FP417 adapted to mechanical harvest, including direct harvest. The flowers are purple and at physiological maturity and at harvest, the pods are yellow (Table 3).

In field experiments, BRS FP417 proved to be resistant to bean common mosaic virus, moderately resistant to rust, and susceptible to bean golden mosaic virus and to angular leaf spot, just as the three check cultivars (Table 3). In addition, BRS FP417 proved to have moderate resistance to anthracnose, similar to BRS Esteio and more resistant than BRS FP403 and IPR Uirapuru; moderate resistance to Fusarium wilt, similar to BRS FP403 and more resistant than BRS Esteio and IPR Uirapuru; intermediate resistance to common bacterial blight, similar to BRS FP403 and more resistant than BRS Esteio and IPR Uirapuru; and intermediate resistance to bacterial wilt, more resistant than the three check cultivars.

Seed production

The cultivar BRS FP417 was registered on 6 October 2022 under number 51208 with the Brazilian Ministry of Agriculture (Ministério da Agricultura, Pecuária e Abastecimento). The production of basic seeds to make available to seed producers will be under the responsibility of Embrapa and of partners selected through public notices of technical cooperation. Additional information can be obtained on the Embrapa page on Internet through the link *https://www.embrapa.br/busca-de-solucoes-tecnologicas*.

Conclusion

BRS FP417 has high yield and excellent commercial-quality grain, standing out especially in the Central and Northeast regions. In addition, it has upright plant architecture and

high resistance to lodging. Another prominent aspect is that it joins resistance to various diseases, because BRS FP417 has excellent levels of resistance to anthracnose and to Fusarium wilt, and intermediate resistance to common bacterial blight and to bacterial wilt. Chemical control is not yet effective for the diseases cited, except for anthracnose.

Based on its performance, BRS FP417 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); the rainy, dry, and winter crop seasons in Region II (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).

Table 3. Agronomic traits and reaction to diseases of the cultivar BRS FP417 compared to those of the black bean check cultivars BRS FP403, BRS Esteio, and IPR Uirapuru.

Cultivar	Cycle	ARCH	LOD	AN	CBB	RU	AS	CM	GM	FOP	CUR
BRS FP417	N	Upright	R	MR	I	MR	S	R	S	MR	I
BRS FP403	N	Upright	R	S	I	MR	S	R	S	MR	S
BRS Esteio	N	Upright	MR	MR	S	MR	S	R	S	S	S
IPR Uirapuru	N	Upright	MR	S	S	MR	S	R	S	S	S

ARCH – plant architecture; LOD – resistance to lodging; AN – anthracnose; CBB – common bacterial blight; RU – rust; AS – angular leaf spot; CM – common mosaic; GM – golden mosaic; FOP – Fusarium wilt; CUR – bacterial wilt; N – normal (85 to 95 days); R – resistant; MR – moderately resistant; I – intermediate resistance; S – susceptible

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