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BRS FC310: CARIOCA COMMON BEAN CULTIVAR WITH SEMI-EARLY CYCLE, UPRIGHT GROWTH HABIT, AND RESISTANCE TO MAJOR DISEASES

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Abstract: BRS FC310 is a semi-early common bean cultivar (mean cycle of 80 days) and features moderate resistance to the major diseases in the common bean crop. It has moderate resistance to anthracnose, rust, common bacterial blight, and bacterial wilt. In addition, it has upright plant architecture and excellent grain commercial and nutritional quality.

Keywords: *Phaseolus vulgaris*, plant breeding, cultivars.

Introduction

In Brazil, dry edible bean/common bean is a staple food; it is the main source of plant protein, especially for the lower income population. Annual production is approximately 2,571 million metric tons, based on the last 10 years, and mean yield is 1,433 kg ha^{-1} (Embrapa Arroz e Feijão, 2020). Approximately 70% of the common bean produced in Brazil is the carioca (cream-colored seed coat with brown streaks) type (Souza et al., 2013). Consumer preference for each commercial type of bean grain varies according to the region and state in Brazil, and the carioca bean is the only type consumed throughout the country. Thus, in the development of new common bean cultivars, it is very important to also select lines that show yield stability in different environments, thus allowing recommendation of cultivars that maintain their competitiveness under various growing conditions and production systems (Torga et al., 2013).

In addition to interest in early maturity and disease resistance, plant breeding programs have

interest in obtaining genotypes with high yield potential and bean grain that is within the commercial standard (Pereira et al., 2019) and has characteristic color and shape (Ribeiro et al., 2019).

The genetic gains obtained by plant breeding for this species are shown in the increase in mean yield in Brazil (Faria et al., 2013), which practically tripled in the last 34 years, from 514 kg ha^{-1} in 1985, the first year reported, to 1,520 kg ha^{-1} in 2019 (Embrapa Arroz e Feijão, 2020). One of the contributions of breeding to the increase in yield was integration of resistance to the main diseases that attack the crop in modern cultivars.

Growers have come to value and require traits such as upright plant architecture and early maturity. Good plant architecture allows mechanized harvest with low harvest loss, lower occurrence of diseases, due to greater aeration in the crop, and better commercial quality of the grain, since there is lower moisture in the pods at the time of harvest. Although advances have been achieved for plant architecture, it is necessary to obtain cultivars that are even more upright than those currently available. Early maturity, for its part, allows rapid return on the capital invested, savings on water and power in irrigated systems, greater flexibility in management of production systems, use of short growing periods, and avoidance of pests, diseases, and periods of water deficit (Melo et al., 2017).

The reduced-cycle cultivars in the carioca group portfolio of Embrapa are currently only one super-early cultivar, BRS FC104 (Melo et al., 2017), with a mean cycle of 65 days, and a cultivar with a semi-early cycle (80-day cycle), BRS Notável (Pereira et al., 2012). This cultivar has high yield, disease resistance, and adaptation to mechanized harvest. Yet, it has a very restricted market because it has a darker grain color than the market requires, and it is mainly used in agroecological systems and family farming operations.

Breeding methods

BRS FC310 originated from the cross between the lines GX 9792-251-2 and ESAL 693, performed at Embrapa Arroz e Feijão in 2002. Still in 2002, the F_1 generation of the population was sown in a screened enclosure. In 2003, in the winter crop season, the population in the F_2 generation was sown in the field in Santo Antônio de Goiás in bulk, and selection was made for plant architecture. In the 2004 dry crop season, the population was advanced in the F_3 generation in Ponta Grossa, PR, in bulk, with selection of individual plants based on resistance to anthracnose, rust, and common bacterial blight. In 2004, in the winter season, the progenies in the $F_{3:4}$ generation were sown in Santo Antônio de Goiás in individual rows, and selection was made based on plant architecture and yield. In 2005, the progenies in the $F_{3:5}$ generation were sown in Santo Antônio de Goiás in the winter, where a new selection of individual plants was made within the best progenies in order to obtain lines.

In 2006, the lines in the $F_{3:5:6}$ generation were sown in Ponta Grossa, PR, in the dry season in individual rows, and lines were selected based on yield and resistance to anthracnose, rust, and common bacterial blight. Also in 2006, the lines in the $F_{3:5:7}$ generation were evaluated in Ponta Grossa in the rainy season, and a new selection was made based on yield and resistance to anthracnose, rust, and common bacterial blight. In 2007, the remaining lines, in the $F_{3:5:8}$, generation, were once more evaluated in Santo Antônio de Goiás in the winter season, and the line LMC207208811 was selected, based on yield and plant architecture. Beginning with this step, the line received the name CNFC 15502, and evaluation in experiments in multiple environments with replications began.

In 2008, the CNFC 15502 line was evaluated in the Progeny Test trial, composed of 100 treatments: 97 new lines and three check cultivars (BRS Estilo, BRS Cometa, and IPR Juriti). A 10 × 10 lattice experimental design was used with three replications, and plots consisted of two 4-m rows. The trials were set up in three environments: Ponta Grossa, in the dry and rainy seasons, and in Santo Antônio de Goiás in the winter season. In these trials, grain yield, plant architecture, resistance to lodging, and reaction

to diseases (anthracnose, rust, and common bacterial blight) were evaluated. Based on these trials, the CNFC 15502 line was selected to participate in the Preliminary Line trial.

In 2009, the CNFC 15502 line was evaluated in the Preliminary Line trial, composed of 46 treatments: 41 new lines and five check cultivars (BRS Estilo, BRS Cometa, BRS Pontal, IPR Juriti, and Pérola). A randomized block experimental design was used with three replications and plots of two 4-m rows. The trials were conducted in five environments: two trials in Santo Antônio de Goiás, GO, and one in Sete Lagoas, MG, in the winter season, and Ponta Grossa, PR, and Carira, SE, in the rainy season. In these trials, grain yield, crop cycle, plant architecture, resistance to lodging, and reaction to diseases (anthracnose, rust, common bacterial blight, angular leaf spot, and fusarium wilt) were evaluated. The CNFC 15502 line was selected from these trials to participate in the Intermediate trial.

In 2011, the CNFC 15502 line was evaluated in the Intermediate trial, composed of 28 treatments: 23 new lines, with cycles ranging from super-early to normal, and five check cultivars (BRS Sublime, BRS Estilo, BRS Pontal, IPR Juriti, and Pérola). A randomized block experimental design was used with three replications and plots of two 4-m rows. The trials were conducted in 10 environments: Santo Antônio de Goiás, GO, one in the dry season and two in the winter season; Ponta Grossa (PR), in the rainy and dry seasons; Carira, SE, and Paripiranga, BA, in the rainy season; Lavras, MG, in the dry season; and Uberlândia, MG, and Sete Lagoas, MG, in the winter season. In these trials, yield, sieve yield, visual appearance, 100-seed weight, 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 from the Preliminary and Intermediate trials led to selection of the CNFC 15502 line for the Value for Cultivation and Use (Valor de Cultivo e Uso - VCU) trial, based on evaluation of 15 environments. In 2012, in the winter season in Santo Antônio de Goiás, seeds were multiplied to obtain a sufficient number to prepare for VCU trials.

In 2013 to 2015, the CNFC 15502 line was evaluated in 92 trials composed of eleven treatments: eight new lines, with cycles ranging from super-early to semi-early, and three check cultivars: BRS Notável (semi-early), IPR Colibri (early), and Carioca Precoce (early). 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 growing systems.

In these trials, the following grain-related aspects were evaluated: yield, sieve yield, 100-seed weight, visual appearance, cooking time, and iron, zinc, and protein contents. The following traits were also evaluated: cycle, plant architecture, resistance to lodging, and reaction to diseases (anthracnose, common bacterial blight, angular leaf spot, fusarium wilt, root rots and bacterial wilt), according to Melo, 2009.

Grain yield and yield potential

Out of the 92 trials set up, 69 (75%) were harvested and achieved the experimental quality standards necessary to be considered in the cultivar registration process in relation to yield data. These 69 VCU trials were conducted from 2013 to 2015 in three of the four regions for recommendation of common bean cultivars (Pereira et al., 2012). The trials were evaluated in region I (Rio Grande do Sul, Paraná, and Mato Grosso do Sul) in the rainy and dry seasons, in Region II (Goiás, Distrito Federal, Mato Grosso, Espírito Santo, Tocantins, 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 FC310 (CNFC 15502) had mean yield of 2,113 $kg.ha^{-1}$, with 99.9% of mean relative performance compared to the mean of the check cultivars BRS Notável and Carioca Precoce (2,155 $kg.ha^{-1}$). Considering each one of the regions, the relative performance was 101.6% in Region 1 (106.5% in the rainy season), 98.5% in Region 2 (109.9% in the dry season), and 101.9% in Region 3 (Table 1). Thus, the grain yield of BRS FC310 is similar to that of the check cultivars evaluated.

Table 1. Grain yield of BRS FC310 compared to the mean of two check cultivars (BRS Notável and Carioca Precoce) in the Value for Cultivation and Use trials by recommendation region and sowing season from 2013 to 2015.

Region	Season	BRS FC310 (kg ha^{-1})	Mean of the check cultivars (kg ha^{-1})	Mean of the relative yields (%)*	Number of environments
I	Rainy	2101.9	2018.9	106.5	7
	Dry	1594.9	1637.6	98.5	11
	Overall	1792.1	1785.9	101.6	18
II	Rainy	2636.1	2668.0	101.0	10
	Dry	1104.3	1017.2	109.9	4
	Winter	2228.3	2355.5	95.5	24
	Overall	2217.3	2296.8	98.5	38
III	Rainy	2256.8	2253.3	101.9	13
Overall	**-**	**2113.8**	**2155.3**	**99.9**	**69**

Region I - RS, SC, PR, MS, and SP; Region II – ES, RJ, GO, DF, MT, TO, BA, and MA; Region III – SE, AL, PE, CE, RN, and PB. *Yield of BRS FC310 in relation to the mean yield of the check cultivars.

The yield potential of BRS FC310, obtained from the mean of the five trials in which this cultivar had the highest yields, was 3,493 kg.ha^{-1}. This estimate shows that the cultivar has high genetic potential and that if the environment is favorable and growing conditions are good, high yields can be achieved.

Commercial, culinary, and nutritional quality of the bean grain

In relation to the grain commercial quality traits, the BRS FC310 cultivar has good sieve yield (83%), and the mean 100-seed weight is 24 grams, better than the IPR Colibri and Carioca Precoce cultivars and similar to BRS Notável, which is the current reference of Embrapa cultivars for carioca grain and semi-early cycle (Pereira et al., 2012). The grain is carioca type (cream-colored with brown streaks) with a flattened elliptical shape and without shine. In relation to visual grain appearance, BRS FC310 proves to be considerably better than BRS Notável, with a very light cream-colored seed coat and light brown streaks. Mean cooking time of BRS FC310 is 37 minutes, less than that of the check cultivars (Table 2).

Table 2. Characteristics of the grain of the BRS FC310 common bean cultivar compared to the check cultivars BRS Notável and Carioca Precoce.

Cultivar	Cooking time (minutes)	Protein content (%)	Fe content	Zn content	100-seed weight (g)	Sieve yield
BRS FC310	37	24.4	67.9	34.7	24.0	83
BRS Notável	43	24.0	61.2	30.9	24.0	85
Carioca Precoce	46	24.0	59.2	32.0	23.0	77

For BRS FC310, the mean protein percentage in the grain (24.4%) was similar to that of the check cultivars. Furthermore, BRS FC310 had higher grain iron content (67.9 mg kg^{-1}) and zinc content (34.7 mg kg^{-1}), 12.8% superior to the mean of the check cultivars for iron content and 10.3% superior for zinc, indicating that it has potential for use as a biofortified bean (Table 2).

Disease resistance

The cultivar BRS FC310 under artificial inoculation is resistant to the common mosaic virus and to pathotypes 73, 89, 91, and 453 of *Colletotrichum lindemuthianum*, the causal agent of anthracnose. However, it is susceptible to pathotype 65. In field trials, it proved to be moderately resistant to anthracnose, rust, common bacterial blight, and bacterial wilt and moderately susceptible to fusarium wilt and angular leaf spot. It showed susceptibility only to the golden mosaic virus, to which only genetically modified germplasm has shown resistance. Thus, BRS FC310 shows the broadest spectrum of resistance to diseases of all the common bean cultivars already developed by Embrapa.

Other traits

BRS FC310 has a semi-early cycle (from 75 to 84 days from emergence to physiological maturity), similar to that of the cultivars BRS Notável and BRS Cometa. It is a bush bean with type II indeterminate growth habit. In relation to plant architecture, BRS FC310 is upright and has good resistance to lodging, being adapted to mechanical harvest, including direct harvest (Table 3).

The flowers are white; and at physiological maturity and at harvest, the pods are yellowish.

Table 3. Agronomic traits and reaction to diseases of the BRS FC310 cultivar compared to the check cultivars BRS Notável and Carioca Precoce.

Cultivar	Cycle	ARCH	AN	CBB	FE	ALS	BCMV	BGMV	FOP	BW
BRS FC310	SE	Upright	MR	MR	MR	MS	R	S	MS	MR
BRS Notável	SE	Upright	MR	MR	MR	S	R	S	MR	MR
Carioca Precoce	E	Semi-prostrate	S	S	MS	S	R	S	S	S

ARCH – plant architecture; AN - anthracnose; CBB – common bacterial blight; FE - rust; ALS – angular leaf spot; BCMV - bean common mosaic virus; BGMV – bean golden mosaic virus; FOP – fusarium wilt; BW – bacterial wilt; E – early cycle; SE – semi-early cycle; R - resistant (score 1); MR – moderately resistant (scores 2 and 3); MS – moderately susceptible (scores 4 to 6); S - susceptible (scores from 7 to 9).

Seed production

BRS FC310 was registered in 2019 under number 41056 with the Brazilian Ministry of Agriculture (Ministério da Agricultura, Pecuária e Abastecimento – MAPA) on 24 Jul. 2019. It is also a protected cultivar, certification number 20200160, obtained from MAPA in 27 Jul. 2020. Basic seed production for availability to seed producers will be under the responsibility of Embrapa and of partners selected through public notices for technical cooperation. Additional information can be obtained through the link https://www.embrapa.br/busca-de-solucoes-tecnologicas or through the telephone 62 3533 2110.

Conclusions

BRS FC310 features moderate resistance to the main diseases in the common bean crop. It is moderately resistant to anthracnose, rust, common bacterial blight, and bacterial wilt, and moderately susceptible to angular leaf spot and fusarium wilt. In addition, it has a semi-early cycle, upright plant architecture, and excellent grain commercial and nutritional quality.

Based on its performance, BRS FC310 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, Mato Grosso, Tocantins, Maranhão, Bahia, Espírito Santo, 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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