CROP BREEDING AND APPLIED BIOTECHNOLOGY

CULTIVAR RELEASE

BRS FC402: high-yielding common bean cultivar with carioca grain, resistance to anthracnose and fusarium wilt

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Abstract: *BRS FC402 is a common bean cultivar of the carioca-grain group with commercial grain quality, suitable for cultivation in 21 Brazilian states. Cultivar has a normal cycle (85-94 days), high yield potential (4479 kg ha^{-1}), 10.1% higher mean yield than the controls (2462 kg ha^{-1}) and resistance to fusarium wilt and anthracnose.*

Key words*: Phaseolus vulgaris, crop breeding, disease resistance, yield stability.*

INTRODUCTION

Brazil is one of the world's leading producers and consumers of common bean (*Phaseolus vulgaris* L.) (FAO 2015). Nationwide, the crop has a high socioeconomic value, for being part of small, medium and large-scale production systems, widely distributed across the country.

In view of the key importance of the crop, common bean breeding programs in Brazil conducted by public and private research institutions have continuously supplied the domestic market with new cultivars (Ramalho et al. 2014, Barili et al. 2016). Primarily, these programs sought the association of desirable traits such as disease resistance, low loss in mechanical harvesting, earliness, higher yield and yield stability, thus contributing to increase crop yields from 810 kg ha^{-1} in 2000 to 1353 kg ha^{-1} in 2013, i.e., a mean yield gain of 67.0%. The mean gains in grain yield obtained by the national common bean breeding program conducted by the Brazilian Agricultural Research Corporation (Embrapa) and partners are in the order of 0.72% per year for the carioca market class (Faria et al. 2013) and 1.1% for the black market class (Faria et al. 2014).

The recommendation of region- and season-specific cultivars has been a challenge due to the low seed use rate. The reasons were the low seed demand and, consequently, low production level, which failed to generate a satisfactory economic return for the seed industry. Thus, a commonly used strategy for the development of new common bean cultivars is to select genotypes with broad adaptation, allowing the recommendation of cultivars that maintain their

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competitiveness under the most diverse growth conditions and production systems.

Embrapa has established agreements with the main common bean breeding programs in Brazil and the world, at different levels of cooperation. These partnerships allow a wide network for the improvement of the crop in Brazil, generating technical/scientific benefits for all partner institutions, but mainly for producers and the Brazilian society. Between 1984 and 2015, Embrapa and partners developed 55 cultivars of different market classes, with an annual mean of 1.8 cultivars, of which 32 were released after the plant variety protection law came into effect. Estimates of Embrapa of the cost-benefit relation of the above common bean breeding program indicated an average return of about 10 dollars in benefits to the Brazilian society, for every dollar invested in the development of cultivars (Alves et al. 2002).

BREEDING METHODS

Cultivar BRS FC402 resulted from the cross between the common bean elite lines LM 96200246 and LP 9632, performed in 2000 by Embrapa Rice and Beans, in Santo Antônio de Goiás (GO). In 2001, the F_1 generation of this population was sown in a greenhouse during the dry growing season. In the same year, generations F_2 and F_3 were also sown in a greenhouse, in the winter and rainy growing season, respectively. In the dry season of 2002, the F_4 generation was grown in Ponta Grossa (PR), in bulk, with selection for upright plant architecture and resistance to anthracnose, rust, common bacterial blight and angular leaf spot. In the rainy season of 2002, the F_5 generation was grown in bulk, also in Ponta Grossa, and individual plants were selected for upright plant architecture and resistance to anthracnose, rust, common bacterial blight and angular leaf spot. In the winter of 2003, $F_{5:6}$ lines were evaluated in Santo Antônio de Goiás, and selected for carioca grain with commercial standard, upright plant architecture, and for resistance to anthracnose, rust, common bacterial blight, and angular leaf spot. One of the selected lines was LM 203200638.

After this stage, line LM 203200638 was evaluated in field trials with replications for grain yield and other important traits, e.g., reaction to diseases and plant architecture. In 2004, LM 203200638 was evaluated together with 159 other elite lines and 9 control cultivars (IPR Juriti, FTS Magnífico, Pérola, Carioca Eté, BRSMG Talismã, BRS Pontal, Iapar 81, Aporé, and BRS Requinte) in field trials with a triple lattice design in Ponta Grossa (dry growing season) and Santo Antônio de Goiás (winter), for resistance to anthracnose, angular leaf spot and for plant architecture and yield.

In 2005, this line was evaluated in the Preliminary Tests in a triple lattice design with plots consisting of two 4.0-m rows, along with 59 other elite lines and 4 control cultivars (BRS Pontal, Pérola, FTS Magnífico, and IPR Jurití). The trials were conducted in four environments: Santo Antônio de Goiás (GO), winter; Lavras (MG), dry season; and Ponta Grossa (PR), rainy and dry growing seasons.

In 2007, LM 203200638 was labeled with the pre-commercial name CNFC 11948 and evaluated in the Intermediate Tests with 29 other elite lines and 5 control cultivars (Pérola, BRS Pontal, BRS Requinte, BRS Cometa, and IPR Juriti) in a randomized block design with three replications and four 4.0-m rows, in eight environments: Santo Antônio de Goiás (GO), Sete Lagoas (MG) and Uberlandia (MG), in the winter growing season; Ponta Grossa (PR), in the rainy and dry seasons; Ijaci (MG), in the dry season; Simão Dias (SE) and Frei Paulo (SE), in the rainy season. The combined analysis of data for grain yield and other agronomic traits qualified the common bean elite line CNFC 11948 for the final field tests, the Tests of Value for Cultivation and Use (VCU).

In 2008, seeds were multiplied for the VCU tests. In 2009 and 2010, line CNFC 11948 was evaluated in 78 field trials with four control cultivars (BRS 9435 Cometa, BRS Estilo, IPR Juriti, and Pérola), in a randomized block design with three replications and four 4.0-m rows, applying the recommended cultivation techniques for the different environments and cropping systems. The two middle rows of each plot were harvested and the grains evaluated for yield, percentage of commercial grain, 100-grain weight, cooking time, and protein content.

Grain yield was measured in kg ha^{-1}, corrected to 13% moisture. The percentage of commercial grain size (sieve yield) was determined in grain samples of 300 g per plot, which were sieved through sieves with oblong holes (width 4.25 mm). The seeds retained on the sieve were weighed and this weight divided by the initial sample weight, to obtain the percentage of seeds with commercial size. From the seeds retained on the sieve, a new 100-seed sample was taken to determine 100-grain weight. In the tests with best results (highest mean yield and lowest variation coefficient), samples were taken from each plot to analyze cooking time and protein content. For cooking time, the grains were soaked in

distilled water at a 1:4 (w/v) ratio at room temperature. After 16 hours, the water was poured off and the grains placed in a Mattson cooker. The cooking time was determined from water boiling until the point when the cooker needles penetrated 50% + 1 of the grains, according to the methodology adapted from Proctor and Watts (1987). The protein content was analyzed in grain flour (grain ground in a ball mill), according to the micro-Kjeldahl method.

In addition, the following agronomic traits were evaluated: lodging tolerance, plant architecture, and disease reaction to: common bacterial blight (*Xanthomonas axonopodis* pv *phaseoli* and *Xanthomonas fuscans pv. fuscans*); 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). For these assessments, rating scales of disease severity were used, as described by Melo (2009), ranging from 1 (absence of pathogen symptoms and signs) to 9 (100% disease severity or plant death).

GRAIN YIELD AND YIELD POTENTIAL

In 78 final field trials (VCU tests) conducted in 2009 and 2010 during the rainy growing season in Sergipe, Alagoas, Pernambuco, Bahia, and São Paulo, at sowing in the dry season in Mato Grosso do Sul and Rio Grande do Sul, at sowing in the rainy and dry seasons in Santa Catarina and Paraná, and at sowing in the rainy, dry and winter growing seasons in Goiás and the Federal District, the cultivar BRS FC402 (CNFC 11948) had a 10.1% higher grain yield than the mean of the control cultivars BRS Estilo and Pérola. The superiority of the mean performance of BRS FC 402, in the three main regions of cultivar recommendation for common bean (Pereira et al. 2009), was 4.5% in Region 3 (Sergipe, Alagoas, Pernambuco, Paraíba, Rio Grande do Norte, Ceará, and Piauí), 15.0% in Region 1 (São Paulo, Mato Grosso do Sul, Paraná, Santa Catarina, and Rio Grande do Sul) and 6.7% in Region 2 (Mato Grosso, Goiás/Federal District, Minas Gerais, Rio de Janeiro, Espírito Santo, Bahia, Tocantins, and Maranhão) (Table 1).

The overall mean yield of BRS FC402 was 2462 kg ha^{-1}, versus 2238 kg ha^{-1} of the control cultivars Pérola and BRS Estilo. Considering the data for each region for official recommendation of common bean cultivars, BRS FC402 exceeded the yield of the control cultivars by 10% in the rainy and dry growing seasons in Region 1, and by 17.7% in the rainy season. In Region 2, BRS FC402 reached a 6.7% higher mean and up to 23% higher mean yield in the dry season (Table 1). In Region 3, the superiority was 4.5%, indicating that BRS FC402 is a broadly adapted cultivar, which can be grown advantageously in the main bean-producing areas of Brazil.

The yield potential of BRS FC402, calculated from the mean of the five best yield test results of this cultivar, was 4,479 kg ha^{-1}. This estimate indicates the high genetic potential of this cultivar and that high yields can be achieved in favorable environments and under good growing conditions.

Based on the agronomic performance, cultivar BRS FC402 was registered as suitable for the rainy and winter growing seasons in the states of Bahia, Mato Grosso and Tocantins; rainy, dry and winter seasons in Goiás, Federal District, Espírito Santo, Rio de Janeiro; dry season in Mato Grosso do Sul; rainy and dry seasons in Paraná, Santa Catarina, São

Table 1. Mean grain yield of the common bean cultivar BRS FC402 compared to the means of the control cultivars Pérola and BRS Estilo in region and season-specific final field trials (Tests of Value for Cultivation and Use - VCU tests) in 2009 and 2010

Region	**Season**	**BRS FC402** (kg ha^{-1})	**Mean yield of control cultivars** (kg ha^{-1})	**Relative mean yield** (%)	**Number of environments**
I	Rainy	2955	2575	117.7	23
	Dry	2119	1946	110.2	13
	Overall	2653	2348	115.0	36
II	Rainy	2594	2467	108.4	16
	Dry	1770	1437	123.0	4
	Winter	2196	2410	93.5	7
	Overall	2368	2299	106.7	27
III	Rainy	2171	2096	104.5	15
Overall	-	2462	2283	110.1	78

Region I – RS, SC, PR, MS, and SP; Region II – MG, ES, RJ, GO, DF, MT, TO, BA, and MA; Region III – SE, AL, PE, PB, CE, RN, and PB.

Paulo and Rio Grande do Sul; and rainy season in Maranhão, Sergipe, Alagoas, Pernambuco, Rio Grande do Norte, Piauí, Ceará and Paraíba.

OTHER AGRONOMIC TRAITS

With regard to the grain quality traits, BRS FC402 has high nutritional value with regular and standard grain size (Table 2). In field trials without fungicide spraying, BRS FC402 reached 87% of the sieve yield, and the mean 100-grain weight was 26 g, similar to the control cultivars Pérola and BRS Estilo (Table 2), indicating the high commercial value of grains. For this reason, it is expected that BRS FC402 presents grain quality parameters higher than those observed in the present work when grown in commercial fields with disease control through fungicide spraying. The mean cooking time of BRS FC402 was 32 min, i.e., slightly higher than that of Pérola and BRS Estilo (31 and 28 min, respectively). The mean grain protein content of BRS FC402 was practically identical to that of the control cultivars (Table 2). Cultivar BRS FC402 has grains with a 7% higher zinc content than the two control cultivars and a 4.5% and 19% higher iron content than Pérola and BRS Estilo, respectively, indicating its strong potential to be used in governmental nutrition programs using biofortificated foods, addressing the nutritional complementation of low-income populations.

Under artificial inoculation, BRS FC402 is resistant to Bean common mosaic virus. In field trials, it proved moderately resistant to anthracnose, rust and fusarium wilt. However, it was susceptible to angular leaf spot, common bacterial blight, bacterial wilt, and BGMV (Table 3).

Cultivar BRS FC402 has a normal cycle (85-94 days from seedling emergence to physiological seed maturity), similar to that of Pérola and BRS Estilo (Table 3). The plants have a semi-upright architecture and an indeterminate growth habit (Type II). This new cultivar is moderately tolerant to lodging and can be used for mechanical and even direct harvesting. The flowers are white and the physiologically mature pods reddish yellow. At harvest maturity, the pods turn sand-yellow. The grains are beige with light brown stripes, a nearly full elliptical shape, not shiny.

Compared to BRS Estilo (Melo et al. 2010) and BRSMG Uai (Ramalho et al. 2016), the most promising and modern cultivars with carioca grain released by Embrapa and partners, BRS FC402 has a higher yield, resistance to anthracnose and wilt fusarium, but the same commercial grain quality as BRS Estilo. For this reason, BRS FC402 is expected to be adopted as a new technical solution for common bean growers throughout Brazil. This cultivar can contribute efficiently to the sustainability of common bean crop in the Brazilian agribusiness. The greatest impact of the introduction of this cultivar is expected mainly for winter cultivation under pivot irrigation and in areas of long-standing and intensive use, for being resistant to fusarium wilt, as well as in the rainy season in high altitude regions and throughout South-central Brazil, for being resistant to anthracnose.

Table 2. Grain traits of the common bean cultivar BRS FC402 compared to the control cultivars Pérola and BRS Estilo in Tests of Value for Cultivation and Use (VCU tests) in 2009 and 2010

Cultivar	Iron content (mg kg^{-1})	Zinc content (mg kg^{-1})	Cooking time (minutes)	Protein content (%)	Sieve yield (%)*	100-grain weight (g)*
BRS FC402	61.8	30.8	32.0	21.3	87.3	26.0
BRS Estilo	51.9	28.7	30.9	21.8	86.0	24.2
Pérola	59.1	28.8	27.8	21.1	84.0	25.6

* Estimates determined in final field trials without disease control, using mesh 11 (4.25 mm).

Table 3. Agronomic traits and disease reaction of the common bean cultivar BRS FC402 compared to the control cultivars Pérola and BRS Estilo

Cultivar	Cycle	PAR	AN	CBB	RU	ALS	BCMV	BGMV	FW	BW
BRS FC 402	N	Semi-upright	MR	S	MR	S	R	S	MR	S
BRS Estilo	N	Upright	MS	S	MR	S	R	S	S	S
Pérola	N	Semi-prostrate	S	S	S	S	R	S	MS	S

N- Normal cycle (85-94 days); PAR- plant architecture; 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. R-Resistant (grade 1); MR- Moderately resistant (grades 2 and 3); MS- Moderately susceptible (grades 4-6); and S Susceptible (grades 7-9).

SEED PRODUCTION

BRS FC402 was registered as a new common bean cultivar by the Ministry of Agriculture, Livestock and Supply (MAPA) on September 30, 2015, under number 34531, and protected in May 06, 2016 under number 20160087. “Embrapa Produtos e Mercado” is in charge of the basic seed production.

CONCLUSIONS

The common bean cultivar BRS FC402 with carioca grain has a normal cycle (85-94 days), high yield, high commercial grain quality and yield stability, and effective resistance to anthracnose and fusarium wilt.

This cultivar is indicated for cultivation in the following States and growing seasons: winter and rainy season in Bahia, Mato Grosso and Tocantins; rainy, dry and winter seasons in Goiás, Distrito Federal, Espírito Santo and Rio de Janeiro; dry season in Mato Grosso do Sul; rainy and dry seasons in Paraná, Santa Catarina, São Paulo and Rio Grande do Sul; and rainy season in Maranhão, Sergipe, Alagoas, Pernambuco, Rio Grande do Norte, Piauí, Ceará and Paraíba.

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