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BRS FC409: COMMON BEAN CULTIVAR WITH HIGH NUTRITIONAL VALUE AND FUSARIUM AND CURTOBACTERIUM WILT RESISTANCE

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Abstract: The common bean cultivar BRS FC409 has high-quality seeds of the commercial group carioca and increased iron, zinc and protein contents. It produces mean yields of 2,048 kg ha^{-1}, can potentially reach 3,755 kg ha^{-1} and is resistant to fusarium wilt, curtobacterium wilt, anthracnose, common bacterial blight and angular leaf spot.

Keywords: *Phaseolus vulgaris*, biofortification, anthracnose, angular leaf spot, common bacterial blight.

Introduction

In the last years, Brazil ranked first in global production (2.7 million tons per year) and consumption of common bean (*Phaseolus vulgaris*) (FAO, 2019). This grain is not only a staple food of the Brazilian population, but also one of the main protein sources in the diet of economically less favored social segments. Among the various common bean seed types, carioca is clearly preferred by most consumers and accounts for about 70% of the domestic consumer market (Pereira et al., 2012).

Iron is fundamental in the formation of hemoglobin and a deficiency of this mineral can cause anemia. Worldwide, 29% of the women aged 15 to 49 years are affected by this deficiency and this percentage is even higher among pregnant

women (38%) and up to 5-year-old children (43%) (Stevens et al., 2013). Zinc is an essential catalytic component of 80 different enzymes, indispensable for sexual maturation, fertility, reproduction and an adequate development of the nervous system. Zinc deficiency can retard growth and cause appetite loss and glucose intolerance. An estimated 17.3% of the world population is affected by Zn deficiency (Wessells et al., 2012). Some strategies are used to overcome these problems, e.g., biofortification, which consists of raising the nutrient contents of food by breeding. Financially, this strategy has proved to be the most viable, requiring no stimulation of consumption and without affecting the original organoleptic characteristics of the food (Ribeiro, 2010).

Biofortification of common bean grains for iron content (FeC) and zinc content (ZnC) is highly promising, sinceit is the most important legume in direct human consumption and already contains relatively high levels of these minerals. Among the already available common bean genotypes in Brazil, two carioca grain cultivars with high FeC and ZnC were identified: BRS Sublime (Wendland et al., 2018) and BRS Cometa (Faria et al., 2008). These cultivars are being indicated for farmers, to obtain grains with higher contents of these minerals. However, it is possible to breed cultivars with even higher FeC and ZnC levels.

Breeding methods

BRS FC409 was derived from a cross between the lines GX 9792-251-2 and ESAL 696, carried out at Embrapa Rice and Beans, in Santo Antônio de Goiás (GO), in 2002. In the same year, the F_1 generation of the population was sown under a screen cover. In the winter of 2003, the F_2 generation was bulk sown in the field, in Santo Antônio de Goiás. In the dry season of 2004, the population was advanced in the F_3 generation in Ponta Grossa (PR), in bulk, with selection of individual plants. In the winter of the same year, the progenies of the $F_{3:4}$ generation were sown in Santo Antônio de Goiás in seperate rows and the best ones were selected. In 2005, the progenies in the $F_{3:5}$ generation were sown in Santo Antônio de Goiás, in the winter, where individual plants within the best progenies were selected again, to establish lines.

In the dry season of 2006, the lines in the $F_{3:5:6}$ generation were sown in Ponta Grossa, in separate lines and lines were selected. In the rainy season of the same year, the lines were evaluated in the $F_{3:5:7}$ generation in Ponta Grossa, and the best were selected. In the winter of 2007, the remaining lines, in the $F_{3:5:8}$ generation, were evaluated again in Santo Antônio de Goiás, resulting in the selection of line LMC207208811. During this process, selection targeted yield, plant architecture and resistance to anthracnose, common bacterial blight and rust. From this stage onwards, the line was named CNFC 15534 and evaluations in replicated experiments were initiated in multiple environments.

In 2008, line CNFC 15534 was evaluated in the progeny test, along with 96 other lines and three controls (BRS Estilo, BRS Cometa and IPR Juriti). A 10 x 10 lattice design was used, with three replications and two 4-m row plots. The experiments were installed in three environments: Ponta Grossa, in the dry and rainy seasons; and Santo Antônio de Goiás, in the winter. In these experiments, and also in the tests described below (preliminary and intermediate), the plants were evaluated for: architecture, lodging tolerance, cycle, sieve yield, yield, visual evaluation and 100-seed weight, as well as disease reaction (anthracnose, fusarium wilt, angular leaf spot, rust, bacterial wilt and common bacterial blight). Based on the combined analysis of these data, line CNFC 15534 was selected to participate in the preliminary test.

In 2009, line CNFC 15534 was evaluated in the preliminary carioca grain trial, along with 40 other lines and five controls (BRS Estilo, BRS Cometa, BRS Pontal, IPR Juriti and Pérola). The experiment was arranged in a randomized block design with three replications in two 4-m row plots, in five environments: Santo Antônio de Goiás (GO) and Sete Lagoas (MG), in the winter, with two trials in Santo Antônio de Goiás; Ponta Grossa (PR) and Carira (SE), in the rainy season. Based on the joint data analysis, line CNFC 15534 was selected to participate in the intermediate test.

In 2011, line CNFC 15534 was evaluated in the intermediate carioca trial, along with 22 other lines and five controls (BRS Sublime, BRS Estilo, BRS Pontal, IPR Juriti and Pérola). The experiment was arranged in a randomized block design with three replications and two 4-m rows, carried out in 10 environments: Santo Antônio de Goiás (GO), in the dry and winter seasons (two trials); Ponta Grossa (PR), in the rainy and dry seasons; Carira (SE) and Paripiranga (BA), in the rainy season; Lavras (MG), in the dry season; Uberlândia (MG) and Sete Lagoas (MG), in the winter. Based on the combined data analysis of the preliminary and intermediate tests, line CNFC 15534 was selected for the Value for Cultivation and Use (VCU) tests, based on the evaluation of 15 environments. In 2010, in the winter in Santo Antônio de Goiás, seeds were multiplied to ensure the availability of a sufficient amount for the VCU tests.

From 2013 to 2015, line CNFC 15534 was evaluated in 128 experiments with 14 treatments, consisting of 10 lines and 4controls: BRS Notável, BRS Estilo, Pérola and IPR 139. A randomized block design with three replications and plots of four rows of 4 m were used, with the technologies recommended for the different environments and cultivation systems. In these experiments, the following grain-related characteristics were evaluated: yield, sieve yield, 100-seed weight, appearance, cooking time and iron, zinc and protein contents. Other trits were assessed on a 1-9 score scale (1-totally favorable phenotype; 9-totally unfavorable phenotype) (Melo, 2009): plant architecture, lodging tolerance and reaction to the diseases: common bacterial blight (*Xanthomonas axonopodis* pv. *phaseoli*); Curtobacterium wilt (*Curtobacterium flaccumfaciens* pv. *flaccumfaciens*); angular leaf spot (*Pseudocercospora griseola*); anthracnose (*Colletotrichum lindemutianum*); rust (*Uromyces appendiculatus*), fusarium wilt (*Fusarium oxysporum* f. sp. *phaseoli*); and common mosaic (CMV) and golden mosaic virus (GMV).

Seed yield was measured in kg ha^{-1} and grain moisture corrected to 13%. The sieve yield was measured as follows: a 300g sample of seeds was taken from each plot, sieved (oblong <4.5 mm holes); the seeds retained in the sieve were weighed and the value divided by the initial sample weight. Another sample of 100 seeds was taken from the retained seeds to determine the 100-seed weight. The cooking time was measured with a Mattson cooker. Protein contents were analyzed based on the nitrogen content, determined by the micro Kjedahl method. The FeC and ZnC were analyzed after acid digestion of organic matter, by flame atomic absorption spectrophotometry.

Grain yield and yield potential

Of the 128 installed VCU experiments, 91 were harvested and the experimental quality of the yield data met the required standards for cultivar registration. These 91 VCU trials were carried out from 2013 to 2015, in region I (Rio Grande do Sul, Santa Catarina, Paraná, São Paulo and Mato Grosso do Sul) in the rainy and dry seasons, in Region II (Goiás, Distrito Federal, Mato Grosso, Espírito Santo, Minas Gerais and Bahia), during the rainy, dry and winter seasons, and in Region III (Sergipe, Alagoas and Pernambuco), in the rainy season. In these experiments, BRS FC409 (CNFC 15534) produced a mean yield of 2,048 kg ha^{-1} (Table 1), lower than that of the controls BRS Estilo and Pérola, considered standards with high yield. The same was observed in regions II and III. However, the cultivar has other advantages, especially with regard to the nutritional seed quality. In region I, the incidence of important diseases that affect common bean is the highest. In this region, cv. BRS FC409 produced a similar yield to that of the controls, which can be explained by the good resistance level of the cultivar against a number of severe diseases affecting the crop in this region.

The yield potential of cv. BRS FC409, calculated from the mean of the five trials with the highest yields, was 3,755 kg ha^{-1}. This shows that in a favorable environment and under good cultivation conditions, high yields can be achieved.

Table 1. Grain yield of cv BRS FC409 compared to the mean of two controls (BRS Estilo and Pérola) in the Value for Cultivation and Use (VCU) tests, according to the recommended cultivation region and sowing time, from 2013 to 2015.

Region	Season	BRS FC409 (kg ha^{-1})	BRS Estilo (kg ha^{-1})	Pérola (kg ha^{-1})	Number of environments
I	Rainy	2,495 a	2,515 a	2,580 a	19
	Dry	1,654 a	1,684 a	1,712 a	15
	Overall	2,124 a	2,149 a	2,198 a	34
II	Rainy	2,181 b	2,529 a	2,563 a	11
	Dry	1,213 b	1,347 a	1,417 a	4
	Winter	2,086 c	2,485 a	2,254 b	29
	Overall	2,031 c	2,392 a	2,255 b	44
III	Rainy	1,910 b	2,061 a	2,193 a	13
Overall	-	**2,048 b**	**2,254 a**	**2,192 a**	**91**

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. Mean scores followed by a common letter in lines do not differ statistically from each other according to the Scott-Knott method at 5% probability.

Commercial and nutritional seed quality

With regard to the technological and industrial seed quality traits, the sieve yield of cv. BRS FC409 is excellent (78%) (Table 2) and 100-seed weight is 25 g, similar to cvs. BRS Estilo and Pérola, which are market references in terms of commercial grain quality. The beans belong to the carioca group (cream-colored with brown streaks), elliptical, without shine. In terms of seed color, cv. BRS FC409 is similar to cv. Pérola, with light cream grain with light brown streaks. The mean cooking time of cv. BRS FC409 is 36 min., intermediate between cvs. BRS Estilo and Pérola. The mean seed protein percentage of BRS FC409 was 24.6% higher than that of the controls. The iron and zinc contents of BRS FC409 seeds were also considerably higher (FeC 66.4 mgkg^{-1}, ZnC 35.3 mgkg^{-1}) than of the controls. The seeds of this cultivar contain approximately 28.0% more Fe, 23% more Zn, and 12.4% more protein than cv. BRS Estilo, one of the most commonly planted in Brazil. For comparison, cv. BRS Sublime, the carioca cultivar that has the highest iron, zinc and protein levels of those already available on the market, has 22.0% more iron, 8% zinc and 2% more protein, also in relation to cv. BRS Estilo.

Table 2. Comparison of grain traits, agronomic traits and disease reaction of common bean cultivars BRS FC409 with the controls Pérola and BRS Estilo.

Cultivar	BRS FC409	BRS Estilo	Pérola
CT	36 b	31 a	40 c
PC	25 a	22 c	23 b
FeC	66 a	52 c	60 b
ZnC	35.3 a	28.8 b	30.0 b
RP	78 a	78 a	75 a
W100	25 a	25 a	26 a
Cycle	N	N	N
ARCH	Upright	Upright	Semi-Prostrate
AN	MS	MS	S
CBB	MS	S	S
RU	MR	MR	MR
ALS	MS	S	MS
CMV	R	R	R
GMV	S	S	S
FW	MR	S	MS
CUR	MR	S	S
RR	S	S	MS

CT – Cooking time (minutes); PC - Protein content (%); FeC - Iron Content (mg kg^{-1}); ZnC - Zinc Content (mg kg^{-1}); RP – Sieved grain yield (<4.5 mm) (%); W100 - 100-seed weight (g). Mean scores followed by a common letter in columns do not differ statistically from each other according to the Scott-Knott method at 5% probability; ARCH- Plant architecture; AN- Anthracnose; CBB- Common bacterial blight; RU- Rust; ALS- Angular leaf spot; CMV- Common mosaic; GMV- Golden mosaic; FW- Fusarium wilt; CUR- Curtobacterium wilt; RR- Root rots; N- Normal cycle; R- Resistant; MR- Moderately resistant; MS- Moderately susceptible; S- Susceptible.

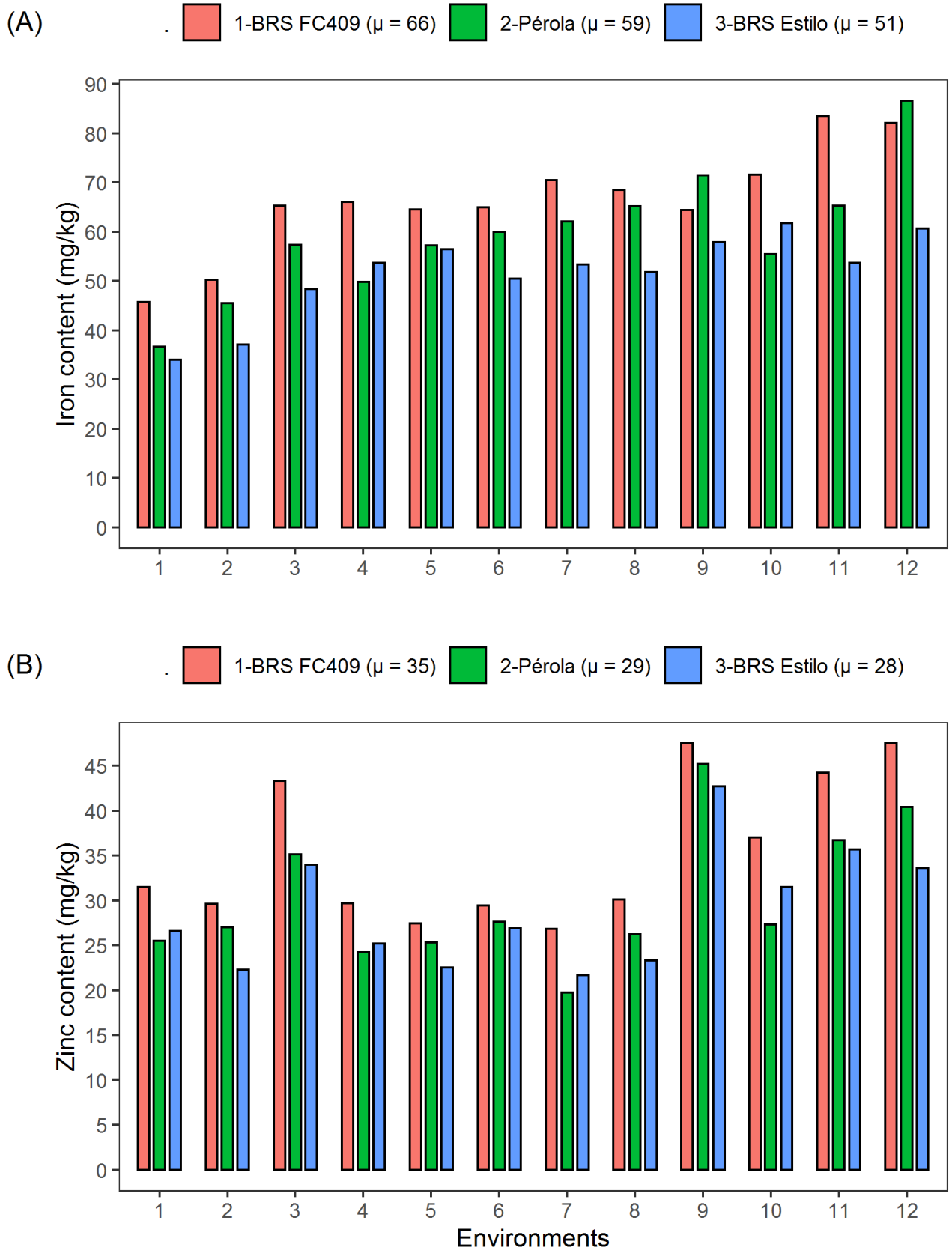

Figure 1. Iron (A) and zinc contents (B) of BRS FC409, BRS Estilo and Pérola cultivars, in different environments (local/state/growing season/year). 1-Brasília, DF rainy/13; 2-Ponta Grossa, PR, dry/13; 3-Brasília, DF, winter/13; 4-Araucária, PR, rainy/13; 5-Dourados, MS, dry/13; 6-Wenceslau Bráz, PR, rainy/13; 7-Ponta Grossa, PR, rainy/13; 8-Ponta Grossa, PR, dry/14; 9-Planaltina, DF, winter/13; 10-Canoinhas, SC, rainy /13; 11-Anápolis, GO, winter/13; 12-Santo Antônio de Goiás, GO, winter/13.

It is noteworthy that there is great variation in these mineral contents of different cultivars depending on the environments. The iron content ranging 46-84 $mgkg^{-1}$ in different environments to BRS FC409 and 34-62 $mgkg^{-1}$ to BRS Estilo (Figure 1A).For the zinc content, the variation was 27-48 $mgkg^{-1}$ to BRS FC409 and 22-36 $mgkg^{-1}$ to BRS Estilo (Figure 1B). Even with this great variation, BRSFC409 presented higher iron and zinc contents than BRS Estilo in 100% of the environments used. Regarding the cultivar Pérola, BRS FC409 was superior in 83% of the environments for iron content and in 100% for zinc content. This indicates that to obtain seeds with higher mineral content, you must use a cultivar with high potential and a suitable environment.

The mean daily consumption of common bean in Brazil is 48 g per person day^{-1} (Conab, 2017). The Pérola cultivar consumed in this amount will provide approximately 20.5% of the daily requirement of iron and 19.7% of zinc. The BRS Estilo cultivar will provide 17.8% of iron and 19.7% of zinc. Considering BRS FC409, 22.9% of the daily requirement of iron and 24.2% of zinc would be provided.

Other traits

Under artificial inoculation, cv. BRS FC409 is resistant to common mosaic virus (Table 2). In field tests, it was moderately resistant to fusarium wilt, curtobacterium wilt and rust and moderately susceptible to anthracnose, common bacterial blight and angular leaf spot. However, susceptibility to golden mosaic and root rot was observed.

BRS FC409 has a normal cycle (85 - 94 days, from emergence to physiological maturity), similarly to the cvs BRS Estilo and Pérola (Table 2). The plants have an upright growth, with indeterminate growth habit (type II) and good lodging tolerance. Mechanical harvesting, including direct harvesting, can be used. The flowers are white and at physiological and harvest maturity, pods are yellowish.

BRS FC409 has an excellent seed quality, with regard to the commercial and nutritional aspects of seeds. The iron, zinc and protein contents of the seeds are higher than of the cultivars available on the market today. In addition, it has upright growth and moderate resistance to fusarium wilt and curtobacterium wilt, which are diseases for which chemical control is inefficient. Thus, this cultivar is indicated for situations where seeds with higher nutritional quality are needed, e.g., in grain supply programs for school lunches, and also in regions where the population is affected by food shortage and mineral deficiencies. Moreover, large companies can offer seeds with higher nutritional value.

Seed production

BRS FC409 was registered in 2019, under number 41057, by the Ministry of Agriculture, Livestock and Food Supply (MAPA). Embrapa is in charge of producing the basic seed to supply seed producers.

Conclusions

The common bean cultivar BRS FC409 has carioca seeds with high commercial and nutritional value and is indicated when the main objective of the farmers is to harvest seeds with a higher nutritional value. In addition, cv. BRS FC409 has a good resistance level against fusarium and curtobacterium wilt and intermediate resistance to anthracnose, common bacterial blight and angular leaf spot.

BRS FC409 is recommended for sowing in the following states and growing seasons: rainy, dry and winter seasons in Goiás, Distrito Federal, Espírito Santo, Rio de Janeiro, Bahia, Mato Grosso and Tocantins; rainy and dry seasons in Mato Grosso do Sul, Paraná, Santa Catarina, São Paulo and Rio Grande do Sul; and rainy season in Sergipe, Alagoas and Pernambuco.

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