

BRS 372 and BRS 416: high-yielding cotton cultivars with multiple disease resistance

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Abstract: BRS 372 and BRS 416 are cotton cultivars with high lint yield and genetic resistance to the main cotton diseases in Brazil, particularly to *Ramularia Leaf Spot*. They have stable yields, good fiber quality and can contribute to a sustainable cotton disease management in tropical environments.

Keywords: *Gossypium hirsutum*, disease resistance, lint yield.

INTRODUCTION


Cotton (*Gossypium hirsutum* L.) is an important commodity in the global agricultural economy. Since the 1980's, the cotton-growing area in the Brazilian savannah (cerrado) was significantly increased, mainly due to the development of genetically improved cotton cultivars, with e.g., higher lint yield and adapted to the cerrado, and because of adjustments and enhanced production systems (Silva Neto et al. 2016). Currently, more than 90% of the Brazilian cotton-growing areas are located in this ecosystem. Particular characteristics of these production systems are extensive areas, high inputs and use of high yielding cultivars that are frequently susceptible to tropical diseases (Ferreira Filho and Alves 2007). In this scenario, diseases previously considered secondary or new diseases, e.g., *Ramularia Leaf Spot* (RLS), caused by the fungus *Ramulariopsis pseudoglycines*, can become epidemic. The latter cotton disease has a high economic relevance since up to eight fungicide applications per season are required to control it in a production area of more than 1.000,000 hectares (Silva et al. 2019).

In Brazil, much effort has been invested in developing new cotton cultivars (Morello et al. 2010, Morello et al. 2012, Morello et al. 2015, Barroso et al. 2017, Suassuna et al. 2018), to ensure high lint yields and the competitiveness of Brazilian cotton on the international market. However, most of the released cultivars are RLS-susceptible. Moreover, the prevalent weather conditions (long periods of high air humidity and daytime temperature between 25 and 30 °C) throughout the growing season in the cerrado ecosystem are conducive to RLS development (Rathaiah 1977). This must have contributed to proliferate the initial inoculum over years and let the disease become epidemic. Consequently, more fungicide sprays per season in cotton fields are now required, increasing the cost for RLS management.

The cotton breeding program of EMBRAPA (Brazilian Agricultural Research Corporation) was established in 1975, and since 1989, cultivars adapted to

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the cerrado have been released. After 2004, efforts were made to develop germplasm resistant to the major diseases, mainly to RLS. For this specific purpose, the breeding program, in partnership with the private sector, was financially supported by FIALGO (Fundo de Incentivo à Cultura do Algodão) and technically by the Fundação Goiás. This paper describes the development of the conventional cotton cultivars BRS 372 and BRS 416 as part of an ongoing effort to create new cotton lines and cultivars with improved yield potential and resistance to one or several diseases, adapted to the Brazilian cerrado.

GENETIC ORIGIN AND DEVELOPMENT

The cultivars BRS 372 and BRS 416 were developed by hybridization and pedigree selection. BRS 372 was originated from a biparental cross of the cotton cultivars Cacique INTA and CNPA ITA 90. The parent Cacique INTA [Mataco INTA x Guazuncho INTA] has a high gin turnout and is resistant to Bacterial Blight and Cotton Blue Disease. Cultivar CNPA ITA 90 (selected from DP Acala 90) is high-yielding, but susceptible to Bacterial Blight and Cotton Blue Disease. Seeds of the segregating population F_2 were obtained from the selfed F_1 hybrid plants. Single plants and rows of progenies were selected by the pedigree method, based on apparent yield potential, high volume instrument (HVI) fiber properties, disease resistance, and the overall plant performance. In the 2001/2002 growing season, in Santa Helena de Goiás - GO, plant '5001' was selected from the segregating F_2 population. The progenies ($F_{2:3}$) of the selected plant (CNPA GO 2002 -5001) were evaluated and individual plants successively re-selected in the growing seasons of 2002/2003, 2003/2004, 2004/2005, 2005/2006 and 2006/2007. In the last, plant '423' was selected and the F_8 progenies of this plant, denominated CNPA GO 2007-423, were evaluated in the 2007/2008 growing season, in which the CNPA GO 2007-423 progenies were bulk-harvested and tested in 2008/2009 as preliminary breeding line (F_9). Line CNPA GO 2007-423 was evaluated as advanced breeding line (F_{10}) in the states of Goiás, Bahia, Mato Grosso and Mato Grosso do Sul, in 2009/2010. In the 2010/2011 and 2011/2012 growing seasons, it was evaluated as final breeding line (F_{11}) in 26 official variety trials for value of cultivation and use (VCU), in the states of Bahia, Goiás, Mato Grosso do Sul, Mato Grosso, Minas Gerais, Maranhão, Piauí, and Rondônia.

Cultivar BRS 416 was derived from a cross between Stoneville 132 [DES 56 x TAMCOT SP37] (Bowman et al. 2006) and Delta Opal [DP 5816 x Sicala 33]. Stoneville 132 is a widely cultivated and Delta Opal a high-yielding cotton cultivar with resistance to bacterial blight and cotton blue disease. 'BRS 416' was derived from a single $F_{3:4}$ progeny row (CNPA GO 2003-1947) after the selection of single plants in the F_2 and F_3 generations. Line CNPA GO 2003-1947 showed some variability and in 2006/2007, an individual plant reselection was performed in the $F_{3:7}$ generation. The progeny CNPA GO 2007-540 (F_8) of the selected plant '540' was evaluated and individual plants were successively re-selected in the 2007/2008, 2008/2009 and 2009/2010 growing seasons. In the last, plant '139' was selected and the F_{11} progeny, denominated CNPA GO 2010-139, was evaluated in Santa Helena de Goiás, in 2010/2011, selected again and bulk-harvested. In 2011/2012, line CNPA GO 2010-139 (F_{12}) was tested as preliminary breeding line. Line CNPA GO 2010-139 was evaluated as advanced breeding line (F_{13}) in eight trials, in the states of Goiás, Bahia, Mato Grosso and Mato Grosso do Sul, in the 2011/2012 growing season. Then, it was evaluated as final breeding line (F_{14}) in 18 VCU trials in Bahia, Goiás, Mato Grosso do Sul, Mato Grosso, Maranhão, Rio Grande do Norte and Ceará, in 2013/2014 and 2014/2015. Parallel to the field performance trials, specific trials without fungicide sprays were carried out to evaluate RLS resistance of both cultivars.

CULTIVAR PERFORMANCE

The cultivars BRS 372 and BRS 416 are picker-type upland cotton with different growth habits, when grown in Santa Helena de Goiás, GO (lat 17° 48' S, long 50° 35' W, alt 562 m asl). BRS 372 is medium/tall, has a mean mature plant height of 125 cm, while BRS 416 plants have a medium size (117 cm), when 50 - 75 g ai ha⁻¹ growth regulator (mepiquat chloride and chlormequat chloride) is applied. BRS 372 is a full-season maturing cultivar; first flowers appear about 65 days after emergence (DAE), first bolls open about 110-120 DAE, and total harvest can be performed at 185 DAE. BRS 416 is a midseason cultivar: first flowers appear about 55-60 DAE, first bolls open about 110 - 115 DAE, and, under the environmental conditions of Santa Helena de Goiás and if harvest aid chemicals are applied, total harvest can be performed at 160-165 DAE.

Plants of both cultivars have trichomes on the leaves and main stem. Leaves and bracts (7 - 12 lobes) are normally

shaped and have glands and nectaries. The first reproductive branch is generally inserted at the fifth node. BRS 372 has short fruiting branches, forming an oblique angle with the main stem, while BRS 416 has normal fruit branches with a more perpendicular insertion in relation to the main stem, resulting in cylindrical or cone-shaped plants, respectively. Flowers have cream-colored petals, anthers, and pollen. Full-size green bolls have greater length than width and are broader in the middle. Bolls have five, occasionally four locks. Open bolls resist shattering but are not stormproof and

Table 1. T-test comparison of cottonseed yield (CY – kg ha⁻¹) and lint yield (LY – kg ha⁻¹) for BRS 372 and FMT 701 (control) in 2010/2011 and 2011/2012 and BRS 416 and FM 910 (control) in the 2013/2014 and 2014/2015 growing seasons

	2010/2011		2011/2012			2013/2014		2014/2015	
	CY	LY	CY	LY		CY	LY	CY	LY
Error	439604	104225	387683	74844	Error	34309	6891	67283	16790
df	612	612	714	714	df	510	510	306	153
N	48	48	56	56	N	40	40	24	12
BRS 372	4365	1945	3837	1718	BRS 416	5131	2256	4810	2171
FMT 701	3847	1653	3635	1589	FM 910	5076	2229	4471	1994
T-value	3.83**	4.44**	1.72	2.51*	T-value	1.33	1.45	4.53**	3.35**

* significant at 5%; ** significant at 1%.

Table 2. Means of cottonseed yield (CY – kg ha⁻¹); lint percentage (LP - %); and lint yield (LY – kg ha⁻¹) of the cotton cultivars BRS 372 and FMT 701 (control), in 26 field trials, in the 2010/11 and 2011/12 growing seasons

Location, planting time and season		BRS 372			FMT 701			PCC†		CV*
		CY	LP	LY	CY	LP	LY	CY	LY	
1 [#] – Second season [#]	10/11 [‡]	2864.3	45.9	1318.0	2930.5	44.4	1303.5	-2.3	1.1	30.8
2 – Second season	10/11	3160.0	43.0	1363.5	3069.8	42.5	1302.8	2.9	4.7	18.8
3 – Main season	10/11	4785.1	44.7	2139.8	4573.2	43.0	1964.9	4.6	8.9	9.2
1 – Main season	10/11	4340.5	43.2	1872.3	3984.8	41.5	1658.3	8.9	12.9	17.5
4 – Main season	10/11	6807.3	46.9	3194.8	6345.0	44.5	2820.8	7.3	13.3	10.4
2 – Main season	10/11	4671.5	45.8	2136.6	4361.6	42.7	1858.4	7.1	15.0	18.1
5 – Second season	10/11	1643.5	41.5	683.6	1982.2	40.9	817.1	-17.1	-16.3	27.5
6 – Main season	10/11	6907.5	44.8	3075.0	6311.3	43.3	2733.8	9.4	12.5	9.7
7 – Main season	10/11	6926.3	46.0	3210.0	3648.8	44.5	1627.5	89.8	97.2	17.6
8 – Main season	10/11	4916.3	45.5	2242.5	3971.3	45.3	1796.3	23.8	24.8	20.3
9 – Main season	10/11	3677.1	39.9	1466.5	3430.3	39.1	1339.5	7.2	9.5	11.5
10 – Second season	10/11	1675.8	38.3	641.5	1551.0	39.3	610.8	8.0	5.0	22.0
11 – Second season	11/12	4052.5	45.0	1824.3	3607.1	44.8	1614.1	12.3	13.0	25.5
1 – Second season	11/12	5990.3	43.9	2626.7	5967.4	43.9	2616.1	0.4	0.4	15.6
12 – Second season	11/12	5130.5	46.3	2377.3	5614.3	44.9	2523.8	-8.6	-5.8	19.9
10 – Second season	11/12	5110.8	43.7	2233.8	4193.5	42.5	1784.6	21.9	25.2	17.2
13 – Main season	11/12	5566.4	44.7	2488.3	5813.6	44.4	2573.1	-4.3	-3.3	13.3
14 – Second season	11/12	4198.3	44.3	1856.2	3832.1	44.2	1692.6	9.6	9.7	18.6
15 – Second season	11/12	2838.8	45.3	1286.5	2604.3	43.8	1140.0	9.0	12.9	12.2
4 – Main season	11/12	5035.5	46.1	2321.8	5600.8	45.9	2575.0	-10.1	-9.8	11.4
2 – Main season	11/12	3537.3	43.1	1526.0	2818.9	41.2	1162.5	25.5	31.3	9.5
7 – Main season	11/12	2932.5	44.5	1305.0	3360.0	42.5	1436.3	-12.7	-9.1	15.0
16 – Main season	11/12	2722.5	44.5	1211.3	2216.3	42.5	937.5	22.8	29.2	20.8
6 – Main season	11/12	3570.0	44.8	1590.0	3082.5	43.3	1327.5	15.8	19.8	19.4
5 – Second season	11/12	3033.8	47.5	1439.3	2306.0	46.0	1059.8	31.6	35.8	12.4
17 – Main season	11/12	2364.3	41.7	986.3	2174.0	39.1	851.5	8.8	15.8	11.1
Mean		4171.5	44.3	1862.2	3821.2	43.1	1658.8	10.5	13.6	

[#] 1=Montividiu GO, 2=Santa Helena de Goiás GO, 3= Mineiros GO, 4= Cristalina GO, 5= Chapadão do Sul MS, 6= Correntina BA, 7= São Desidério BA, 8= Formosa do Rio Preto BA, 9= Naviraí MS, 10 = Primavera do Leste MT, 11= Palmeiras de Goiás GO, 12= Ipiranga do Norte MT, 13= Campo Verde MT, 14= Sorriso MT, 15= Sinop MT, 16= Riachão das Neves BA, 17= Dourados MS; [‡]Main season = Cotton sown between November and December, Second season = Cotton sown between January and February, after soybean harvest; ^{*}10/11 = 2010/2011, 11/12 = 2011/2012. * CV - Coefficient of variation (%) for cottonseed yield (kg ha⁻¹); † PCC - Percentage in comparison to the control cultivar (increase or decrease).

are suitable for picker harvesting. Lint and fuzz are white. The mean boll weight of BRS 372 and BRS 416 was 6.0 and 5.2 g, respectively.

Cultivars BRS 372 and BRS 416 have a high resistance level against bacterial blight [caused by *Xanthomonas citri* subsp. *malvacearum*], cotton blue disease [caused by *Cotton leafroll dwarf virus*-CLRVD] and Ramularia leaf spot [caused by *Ramulariopsis pseudoglycines*]; BRS 372 is moderately resistant to the *Fusarium oxysporum* f. sp. *vasinfectum* - *Meloidogyne incognita* complex, while BRS 416 is moderately susceptible; and both are susceptible to ramulosis [caused by *Colletotrichum gossypii* var. *cephalosporioides*]. Based on data of cv. BRS 372 from five independent field trials without fungicide spraying, a mean RLS disease score of 1.17 was recorded on a scale from 1 (immune) to 5 (highly susceptible). For cv. BRS 372, fungicide foliar sprays were not necessary to avoid losses caused by ramularia leaf spot (Silva et al. 2017). Cultivar BRS 416 had a mean RLS score of 1.3 across three independent field trials, on the same 1-5 disease score scale.

Disease resistance to cotton blue disease and bacterial blight was confirmed by molecular markers. The fluorochrome-labeled SSR primers DC20027 and CIR246 were used for genotyping. These primers were selected because they are physically linked to resistance genes that confer total resistance to blue disease and bacterial blight. Cultivar Delta Opal was used as resistant control. Polymerase chain reactions (PCR) were performed in a multiplex system using the Kit PCR Multiplex (Qiagen), as described by Carvalho et al. (2017). For marker CIR 246, the control (Delta Opal), all BRS 372 samples and 98% of the BRS 416 samples amplified a 146-bp band, associated with the bacterial blight resistance gene B12 (Xiao et al. 2010). In 2% of the BRS 416 samples, which were heterozygous but resistant, the 146/156 band pattern was observed. All samples of BRS 372, BRS 416 and Delta Opal (control) amplified a 202-bp band for marker DC 20027. This band pattern is associated with a resistance gene against the blue disease (Fang et al. 2010).

Significant paired comparison t-tests were used to determine significant differences between the test cultivars and control in each growing season. In 2010/2011 (Table 1), BRS 372 yielded significantly more cottonseed (4365 kg ha⁻¹) and lint (1945 kg ha⁻¹) than FMT 701 (3847 and 1653 kg ha⁻¹, respectively). In 2011/2012, BRS 372 produced significantly more lint than FMT 701 (Table 1). Averaged across the 26 VCU trials in central and northeastern Brazil, in 2010/2011 and

Table 3. Means of cottonseed yield (CY – kg ha⁻¹); lint percentage (LP - %); and lint yield (LY – kg ha⁻¹) of the cotton cultivars BRS 416 and FM 910 (control), in 18 field trials, in the 2013/14 and 2014/15 growing seasons

Location, planting time and season	BRS 416			FM 910			PCC†		CV*	
	CY	LP	LY	CY	LP	LY	CY	LY		
1 [#] – Main season [¶]	13/14 ^x	5341	44.3	2367	5288	43.2	2287	1.0	3.5	15.6
2 – Main season	13/14	5997	41.8	2507	5474	42.0	2298	9.5	9.1	13.1
3 – Main season	13/14	4689	44.0	2064	4691	43.7	2048	0.0	0.8	18.8
4 – Main season	13/14	4035	-	-	4030	-	-	0.1	-	3.84
5 – Main season	13/14	7612	39.9	3037	7664	40.5	3104	-0.7	-2.1	15.8
6 – Main season	13/14	4692	41.6	1952	3508	43.2	1515	33.8	28.8	36.4
7 – Second season	13/14	4222	42.3	1786	4003	41.1	1645	5.5	8.6	14.5
8 – Main season	13/14	4039	39.4	1591	3946	40.0	1578	2.4	0.8	19.6
9 – Main season	13/14	6774	40.6	2750	6771	42.2	2857	0.0	-3.7	9.79
10 – Second season	13/14	5531	40.7	2251	5920	40.1	2374	-6.6	-5.2	8.07
11 – Main season	13/14	2101	41.5	872	2060	41.9	863	2.0	1.0	28.2
12 – Main season	13/14	5002	41.6	2081	4943	41.8	2066	1.2	0.7	13.1
13 – Main season	14/15	3752	43.2	1621	3194	40.4	1290	17.5	25.2	15.4
3 – Main season	14/15	4023	44.2	1778	4461	41.7	1860	-9.8	-3.3	30.5
5 – Main season	14/15	6424	40.9	2627	6148	39.8	2447	4.5	10.0	17.4
14 – Main season	14/15	4413	-	-	4438	-	-	-0.6	-	24.1
11 – Main season	14/15	5877	-	-	5542	-	-	6.0	-	12.4
10 – Second season	14/15	4369	-	-	3044	-	-	43.5	-	22.2
Mean		4938.5	41.9	2091.7	4729.2	41.5	2016.6	6.1	5.3	

[#]1= Correntina BA, 2= São Desidério BA, 3= Riachão das Neves BA, 4= Mata Roma MA, 5= Apodi RN, 6= Missão velha CE, 7= Mineiros GO, 8= Santa Helena de Goiás GO, 9= Cristalina GO, 10= Primavera do Leste MT, 11= Campo Verde MT, 12= Chapadão do Sul MS, 13= Luís Eduardo Magalhães BA, 14= Santo Antônio de Goiás GO; [¶]Main season = Cotton sown between November and December, Second season = Cotton sown between January and February, after soybean harvest; ^x13/14 = 2013/2014, 14/15 = 2014/2015. * CV - Coefficient of variation (%) for cottonseed yield (kg ha⁻¹); † PCC - Percentage in comparison to the control cultivar (increase or decrease).

Table 4. Agronomic traits and fiber quality of BRS 372, BRS 416, FMT 701 (control), and FM 910 (control)

Traits	BRS 372	BRS 416	FMT 701	FM 910
First flower (DAE)*	65	55-60	-	-
First open boll (DAE)*	110-120	110-115	-	-
Boll weight (g) ^a	6.0	5.2	-	-
Weight of 100 seeds (g) ^a	8.9	8.2	-	-
Fiber length (UHML) (mm) ^a	29.8	29.7	29.0	29.5
Uniformity index (ML/UHML - %) ^a	83.5	85.2	84.0	84.4
Strength HVI (gf tex ⁻¹) ^a	29.5	29.2	30.2	30.2
Micronaire reading ^a	4.4	4.8	4.5	4.9
Elongation (%) ^a	6.6	6.3	6.3	6.2
Reflectance – Rd (%) ^a	77.5	76.7	78.3	79.4
Yellowness (+ b) ^a	8.0	7.9	7.5	8.9
Short fiber index (%) ^a	7.2	7.0	7.1	6.5
Cotton leafroll dwarf virus (CLRDV) ^b	0.0	0.0	0.0	0.0
Atypical form of CLRDV ^c	1.5	1.3	3.5	1.6
Ramularia leaf spot ^c	1.0	1.2	3.0	2.8
Bacterial blight ^{c,d}	1.0	1.0	1.0	1.0
Ramulosis ^{c,e}	3.7	2.5	-	2.6

* Data recorded in Santa Helena de Goiás (lat 17° 48' 15" S, long 50° 35' 43" W, alt 562 m asl) – GO.

^a Means of 26 (BRS 372 and FMT 701) or of 18 (BRS 416 and FM 910) field trials in several environments (States of Goiás, Bahia, Mato Grosso, Mato Grosso do Sul, Maranhão, Rio Grande do Norte and Ceará); ^b Incidence (%) of plants with cotton blue disease symptoms - data of two assays without control of virus vector (*Aphis gossypii*), confirmed by the SNP marker (Fang et al. 2010); ^c Disease severity (grades from 1 = resistant to 5 = highly susceptible); ^d For bacterial blight, resistance confirmed by the SNP marker (Xiao et al. 2010); ^e Data of plants artificially inoculated with *Colletotrichum gossypii* var. *cephalosporioides* in a field trial.

2011/2012, BRS 372 produced 1862.2 kg lint per hectare, i.e., 13.6% higher lint yield than the control cultivar FMT 701. Higher lint productivity is related to the lint percentage. BRS 372 had a mean lint percentage of 44.3% (ranging from 38.3 to 47.5%) across the trials (Table 2). The HVI measurements indicated that the cultivar has the desirable physical properties of a medium fiber length cultivar: mean micronaire reading of 4.4; mean fiber length (UHML) 29.8mm; mean relative strength 29.5 gf tex⁻¹; reflectance of 77.5%; yellowness (+b) 8.0 and short fiber index 7.2 (Table 4).

The evaluations in 18 VCU field trials in central and northeastern Brazil in 2013/2014 and 2014/2015 showed that cultivar BRS 416 produced 6.1% more cottonseed and a 5.3% higher lint yield than cultivar FM 910. In 2013/2014, there were no significant differences between BRS 416 and FM 910 for cottonseed yield and lint yield (Table 1). However, in 2014/2015, BRS 416 yielded significantly more cottonseed (4810 kg ha⁻¹) and lint (2171 kg ha⁻¹) than FM 910 (4471 and 1994 kg ha⁻¹, respectively). The mean lint percentage was 41.9% for cultivar BRS 416 and 41.5% for FM 910 (Table 3). Cultivar BRS 416 is a medium staple upland cotton, according to the HVI fiber properties: micronaire reading 3.9 - 4.8; fiber length (UHML) 27.6 - 31.2 mm; relative strength 27.4 - 29.2 gf tex⁻¹; reflectance 71.5 - 80.5%; yellowness (+b) 7.3 - 8.8; short fiber index 5.1 - 8.7. The mean data of fiber quality of 18 field trials are summarized in Table 4.

SEED MAINTENANCE AND DISTRIBUTION

Cultivars BRS 372 and BRS 416 are protected (certificates no. 20140173 and 20170145, respectively) by the Brazilian Ministry of Agriculture, Livestock and Food Supply. Genetic seed is available at Embrapa Cotton.

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