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Impact of transgenic conversion on the characteristics of Burkina Faso cotton

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Genetically modified cotton (GMC) was compared with two conventional cultivars, using data from trials and commercial farms. Objectives were to highlight disparate agronomic and technological performance parameters and identify perspectives to Burkina Faso comeback to GMC. Results showed that compared materials are similar for most agronomic characteristics, except fiber percent. As this important parameter is concerned, GMC outperformed conventional cultivars in trials (+1.2 to +2.2%) and some commercial fields by +0.3, +0.5, +0.6 and +1% at Banfora, Koudougou, Houndé and Dédougou, respectively. For fiber quality, they did not show significant difference in maturity, micronaire, uniformity index, elongation, short fiber index, reflectance and yellowness. For two important parameters in cotton fiber marketing, Upper Half Mean Length and Strength, GMC was highly handicapped by -1.43 to -2.09 mm and -19.70 to -40.67 kN m Kg^{-1} compared to conventional cultivars, in commercial production. In trials, differences averaged -1.75 mm and -32.34 kN m Kg^{-1}. Differences between compared materials are genetic, due to failure in recovering important characteristics after the transgenic conversion. Local GMC cultivars could be an asset if more perfectly achieved, on site selected and pre-release evaluated, to take into account local production particularities.

Key words: Genetic conversion, *Bt* cotton, agronomic characteritics, fiber properties, Burkina Faso.

INTRODUCTION

Cotton is a strategic agricultural product of critical importance to many African countries, with small-scale producers in small acreages and low intensification (Hussein et al., 2005). For several decades, the application of chemical insecticides has been used to control pest attacks in commercial cotton production. In 1998, cotton production was strongly affected by the development of resistance of several pests, mainly *Helicoverpa armigera*, to efficient chemical products formerly known as pyrethroids (Martin et al., 2000; Omer et al., 2009). In the 2000s, to adopt genetically modified cotton (GMC) represents a solid alternative to chemical insecticides that had become less effective; that is still actual today (Vitale et al., 2008; James, 2017).

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At the request of the cotton interprofession of Burkina Faso (AICB), experiments were conducted from 2003 to 2007 by the Institute of Environment and Agricultural Research (INERA) to investigate the impacts of prospective adoption of GMC technology. The trials were initially conducted with *Bt* (*Bacillus thuringiensis*) transgenic cultivars of American origin (Coker 312 *Bt* and DP50 *Bt*), then during the 2006/2007 campaign with local GM cultivars. The indirect transformation route, by crossing with the already transformed cultivar Coker 312, was used to introgress two *Bt* transgenes (Cry1Ac-MON531 and Cry2Ab-MON15985 BGII™) into two cultivars from Burkina Faso and one introduction cultivar from Togo (Stam 59 A). The introgression of FK290 failed, and those which succeeded (FK37 and Stam 59 A) were two times backcrossed (BC2), followed by selection process conducted by Monsanto in the USA.

Preliminary studies reported a potential increase in field yield of around 30%, biological efficacy of transgenes on phyllophagous and carpophagous target insects which include *H. armigera*, and a reduction of four insecticide applications (from 6 to 2) in the case of an agreement to popularize *Bt* varieties in Burkina Faso (Cabanilla et al., 2005; Vitale et al., 2008). The evaluation of fiber properties from pre-release trials was not sufficiently considered. Results under research station conditions revealed no gain in terms of fiber length and strength into both converted cultivars compared to their near-isogenic conventional. There was a mitigated gain in fiber percent as FK37 BG2 was concerned (INERA, 2006). But, seeing in GMC a miracle solution to pest infestation with a hope of competitive advantage, Burkina Faso becomes in 2008 the second African country after South Africa to adopt GMC. Seed production is launched the same year, followed in 2009 by commercial cultivation on 418,200 ha. During 2015 campaign, GMC coverage rate reached 62.53% that is, 325,425 of the total 520,428 ha planted (SOFITEX, 2017; Vitale et al., 2010). By the first years of large-scale release coupled with unfavorable worldwide conjuncture of oversupply and price depression highlighted problems in Burkina Faso *Bt* cotton fiber technology (Fok, 2016). The venture was suddenly suspended in 2016; the cotton sector blaming GMC to underperform as expected, especially for fiber quality (AICB, 2015, 2019). However, it is not excluded even it is very probable that Burkina Faso returns back to GMC cultivation.

This study to assess the impact of the transgenic conversion on the characteristics of Burkina Faso cotton was based on data collected from producer farms of 2015 commercial production and from trials conducted in research station trials in 2016, 2017 and 2018. The objectives were to *i*) highlight disparate agronomic and technological performance parameters between conventional cotton cultivars and *Bt* ones and *ii*) identify perspectives in the eventuality of Burkina Faso's returning back to GMC.

MATERIALS AND METHODS

Plant material

The plant materials consisted of three varieties that is, Burkina Faso transgenic cultivar (FK95 BG2 or FK37 BGII) and its conventional near-isogenic recurrent parent (FK37) plus a new conventional cultivar designated FK64. In 2006, FK37 was used to introgress *Bt* transgenes conferring resistance to cotton pests (MON15985). Conversion was done by crossing with an already *Bt* introgressed American cultivar Coker 312, follow by two backcrosses with FK37, that gave rise to FK95 BG2. FK64 is in the process of being launched in commercial production because of its improved fiber characteristics above the current cultivars, especially fiber lengh.

Data recording from commercial fields

In December 2015, one kilogram (1 Kg) seed cotton samples of FK95 BG2 and FK37 were collected at producers' farms from 34 districts in seven cotton regions of SOFITEX (Société Burkinabè des Fibres Textiles) which covers 80% of Burkina Faso cotton belt (Figure 1). Three cotton producer groups (CPG) were randomly selected by district and then three producers by CPG. Within CPG, fields of producers growing the two types of cotton were sampled preferentially and if any case, producers having complementary types were considered.

Collected samples were ginned with a 20-saw laboratory gin to record one agronomic variable that is, fiber percent (FP). Thereafter, 100 g of cotton fiber per sample were evaluated on an integrated measurement chain (IMC), following ISO/DIS 139 laboratory conditioning and testing conditions. Commonly used major fiber properties that is, micronaire (Mic), maturity (Mat), length (UHML), uniformity (UI), short fiber content (SFI 12.7 mm), strength (Str), elongation (Elo), degree of reflectance (Rd) and yellowness (+b), were recorded as variables.

Data recording on trials at research station

Three trials were conducted (2016, 2017 and 2018), at Farako-Bâ research station to compare FK95 BG2 to FK37 and FK64. This station is located in the western cotton belt of Burkina Faso, between isohyets 800 and 1200 mm, at 405 m of altitude, 4°20'W of longitude and 11°06'N of latitude. Soils are lexisols with low clay and organic matter content, with a notable deficiency in nitrogen and phosphorus (Bado, 2002). Climate is South Sudanian type with a cumulative rainfall of 924 mm in 57 rainy days, 766.5 mm in 52 rainy days and 1303.8 mm in 70 rainy days in 2016, 2017 and 2018, respectively.

Trials were a Fisher block design with 3 replications. Two meters alley was separating replications and each elementary plot was composed of three rows of 20 m. Distance was 0.40 m between seedlings holes and 0.80 m between rows. A thinning to 2 plants/hill was done two weeks after emergence, and then all fertilization and phytosanitary practices were carried out, from sowing to harvest, in accordance with recommendations for cotton production in Burkina Faso.

Five major agronomic variables were measured i.e. the first flowering date (FFD)/first boll opening date (FBOD) that is, the date by which 50% of the plants in each elementary plot produced at least one flower/one open boll; the cotton seed yield (RDT) deduced using harvested cotton from central row of each elementary plot; the seed index (SI) or an average weight of 5 samples of 100 undelinted seeds and the fiber percent (FP) measured after ginning 200 g seed cotton per elementary plot. For fiber properties, as on samples from commercial fields, the same commonly used major fiber properties (Mic, Mat, UHML, UI, SFI

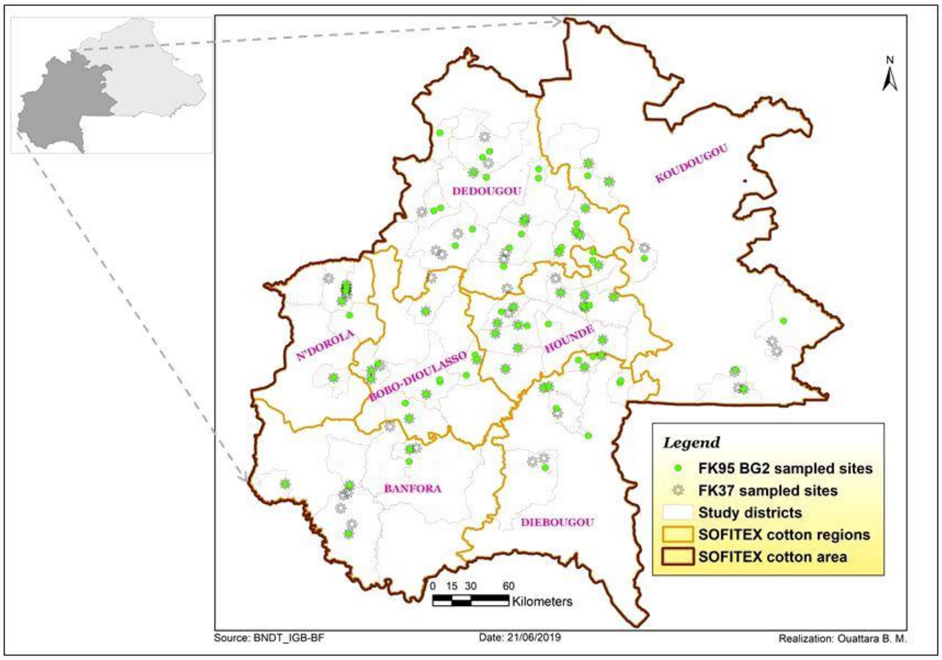

Figure 1. SOFITEX cotton zone, regions and departments including study sampled sites.

12.7 mm, Str, Elo, Rd and +b) were recorded in the same IMC, following the same laboratory conditions.

Data analysis

From data collected via producers' fields, so-called GMC samples expressing less than 95% of presence of both transgene proteins Cry1Ac and Cry2Ab, and conventional samples with more than 5% contamination by *Bt* transgenes were eliminated. Then, remaining data were subject to descriptive statistics analysis, using R software. Data from trials have been analysed through an analysis of variance (ANOVA), using the SISVAR 5.1 Build 72 software. The averages were compared by the Scott-Knott test at 5% threshold level.

RESULTS

Results concerning certain fiber properties that is, Mat, SFI, Elo and reflectance never showed statistical difference between the compared materials, in trials as well as in commercial production (Results not presented in this article).

Agronomic characteristics to compare GMC cultivar to conventional ones

The results of descriptive analysis on fiber percent (FP), the single agronomic characteristic recorded in commercial production, revealed differences between the compared cultivars. As showed in Table 1, the GMC compared to FK37 presented positive margins in 4 cotton regions (+0.3% in Banfora, +0.5% in Koudougou, +0.6% in Houndé, +1% in Dédougou) and negative ones in 3 regions (-0.1, -0.1 and -0.5%). When we considered SOFITEX zone as a whole, the margin remains positive for GMC of +0.1% (Table 2).

From trials, the ANOVA results showed significant differences for FP ($p = 0.02$ and $p = 0.00$) to the advantage of the GMC compared to FK37 and FK64 in 2016 as well as in 2017 and 2018 (Table 3). On the other hand, there are no significant differences between the GMC and conventional cultivars for the opening of the first flower (FFD) or first boll (FBOD). Seed index (SI) in 2016 and cotton seed yield in 2018 revealed significant difference, with better value for FK64 while FK37 and FK95 BG2 were similar in terms of SI, and with the lowest value for FK64 while FK37 and FK95 BG2 gave similar values in terms of yield that is, RDT (Table 3). It can also be noted that in 2017, the values of RDT, SI and FP were in order of magnitude lower than those of 2016 and 2018 as a long drought affected the western area of Burkina Faso during cotton maturation in 2017; all studied materials had been affected similarly and interaction Year*Cultivar effect was never significant (Table 3).

Fiber properties to compare GMC cultivar to conventional ones

Analysing fiber properties data from commercial farms and by cotton region (Table 1) revealed that GMC exhibited net negative margins compared to FK37 for

Table 1. Descriptive analysisof agronomic characteristics and fiber properties of samples collected in 2015 in commercial farms from SOFITEX cotton regions.

Var.	Desc.Par.	KG		HD		DD		ND		DB		BO		BA	
		Conv	***Bt***	**Conv**	***Bt***	**Conv**	***Bt***	**Conv**	***Bt***	**Conv**	***Bt***	**Conv**	***Bt***	**Conv**	***Bt***
Pf	nb	20	38	26	42	18	43	24	36	10	25	36	46	23	35
	min	43.0	41.7	40.3	42.7	39.3	40.3	42.3	41.0	42.3	42.0	42.3	42.7	43.3	44.3
	max	47.0	46.7	46.3	48.0	45.3	46.7	48.0	48.3	47.0	46.3	48.0	48.0	47.7	47.3
	aver	44.6	45.1	44.2	44.8	43.3	44.3	44.8	44.7	44.9	44.4	45.2	45.1	45.5	45.8
	marg		**+0.50**		**+0.60**		**+1.00**		**-0.10**		**-0.50**		**-0.10**		**+0.3**
	cv	0.02	0.03	0.03	0.03	0.03	0.03	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.02
Mic	min	3.4	4.1	3.8	3.8	3.9	4.2	3.6	3.5	3.7	3.5	3.4	3.6	3.7	4.2
	max	5.2	5.3	5.1	5.0	5.1	5.2	4.8	5.2	4.9	5.3	4.7	5.8	4.8	5.1
	aver	4.4	4.7	4.3	4.5	4.5	4.7	4.1	4.4	4.3	4.5	4.1	4.4	4.2	4.7
	marg		**+0.24**		**+0.15**		**+0.15**		**+0.3**		**+0.13**		**+0.32**		**+0.5**
	cv	0.10	0.06	0.09	0.07	0.06	0.06	0.07	0.10	0.09	0.09	0.07	0.08	0.06	0.06
UHML	min	27.1	24.9	26.4	25.3	26.9	24.0	27.0	25.3	28.1	25.4	26.2	24.9	26.6	23.9
	max	30.6	30.0	30.3	29.6	30.0	29.4	30.5	30.7	31.0	29.3	30.2	29.5	31.0	28.5
	aver	28.9	27.5	28.7	27.3	28.8	27.1	29.0	27.3	29.3	27.2	28.5	26.6	28.5	26.6
	marg		**-1.47**		**-1.43**		**-1.65**		**-1.8**		**-2.09**		**-1.87**		**-1.9**
	cv	0.03	0.04	0.03	0.03	0.03	0.04	0.03	0.04	0.03	0.03	0.03	0.04	0.03	0.04
Str	min	260.7	247.0	259.7	225.4	260.7	223.4	264.5	230.5	286.2	248.0	271.5	225.4	260.6	239.6
	max	383.2	329.3	337.1	345.9	385.1	331.2	327.3	315.2	374.4	296.0	331.2	314.6	344.0	307.9
	aver	310.7	291.1	301.8	271.5	313.6	277.3	299.0	263.6	312.6	272.4	293.0	266.6	291.8	266.6
	marg		**-19.7**		**-30.5**		**-36.6**		**-35.4**		**-40.7**		**-26.8**		**-25.3**
	Cv	0.1	0.07	0.07	0.1	0.1	0.07	0.05	0.07	0.07	0.05	0.05	0.07	0.07	0.06
UI	min	80.4	77.2	76.2	76.9	78.9	76.0	79.47	76.98	79.2	78.3	76.7	77.9	78.20	77.65
	max	84.2	83.6	83.4	82.6	83.9	83.3	84.98	83.44	84.6	82.3	83.4	82.7	83.25	81.97
	aver	82.6	81.0	81.2	80.6	82.0	80.8	82.00	80.85	82.0	80.4	80.9	80.2	80.94	79.69
	marg		**-1.64**		**-0.57**		**-1.17**		**-1.16**		**-1.58**		**-0.66**		**-1.25**
	cv	0.01	0.02	0.02	0.02	0.02	0.02	0.01	0.02	0.02	0.01	0.02	0.01	0.01	0.01
b+	min	7.5	7.1	7.3	6.8	7.1	6.7	7.00	7.16	6.7	7.0	7.2	7.0	6.99	6.12
	max	10.9	10.1	9.8	10.7	9.6	9.4	10.47	10.44	10.3	10.0	9.9	10.1	9.52	9.42
	aver	8.7	8.7	8.5	8.3	8.4	8.0	8.90	8.55	8.1	8.4	8.3	8.5	8.33	8.01
	marg		**+0.01**		**-0.16**		**-0.32**		**-0.35**		**+0.26**		**+0.17**		**-0.33**
	cv	0.08	0.07	0.07	0.09	0.08	0.07	0.11	0.10	0.16	0.11	0.08	0.08	0.08	0.10

Cotton regions are KG = Koudougou, HD = Houndé, DD = Dédougou, ND = N'Dorola, DB = Diébougou, BA = Banfora and BB =Bobo; Vegetal materials are *Bt* = FK95 BG2 and Conv = FK37; Descriptive analysis parameters (Desc. Par.) are nb = number of individuals, min = minimum, max = maximum, aver = average, marg = margin, cv=variation coefficient. Var = studied variable.

length (-1.43 to -2.09 mm), strength (-19.7 to -40.7 kN m Kg^{-1}) and uniformity (-0.57 to -1.64%). The margin was positive for Mic (+0.13 to + 0.53) whereas fluctuating for +b that is, positive in the cotton regions of Koudougou, Diébougou and Bobo-Dioulasso and negative in the remaining regions (Table 1). In overall analysis, with all cotton regions taken together, trends are maintained. In other words, in SOFITEX zone, the GMC fibers had a short length (-1.7 mm), low tenacity (-28.4 kN m Kg^{-1}), low uniformity (-0.95%) compared to those of FK37 (Table 2). GMC fibers had an advantage for Mic (+0.28) and yellowness index +b (-0.10).

At trials level, the results showed statistically significant differences only in fiber length (UHML) and strength (Str). Differences were highly significant for UHML (p = 0.00) in 2016 as well as in 2017 and 2018, whereas for Str they

Table 2. Aggregate Sofitex zone descriptive analysis.

Var.	Desc. Par.	SOFITEX zone	
		Con	*Bt*
Pf	nb	155	247
	min	39.3	40.3
	max	48.0	48.3
	aver	44.7	44.8
	marg		**+0.1**
	cv	0.0	0.0
Mic	min	3.4	3.5
	max	5.2	5.8
	aver	4.3	4.5
	marg		**+0.2**
	cv	0.1	0.1
UHML	min	26.2	23.9
	max	31.0	30.7
	aver	28.8	27.1
	marg		**-1.7**
	cv	0.0	0.0
Str	min	259.7	223.4
	max	385.1	345.9
	aver	301.8	273.4
	marg		**-28.4**
	cv	0.1	0.1
UI	min	76.2	76.0
	max	85.0	83.6
	aver	81.6	80.6
	marg		**-1.0**
	cv	0.0	0.0
b+	min	6.7	6.1
	max	10.9	10.7
	aver	8.5	8.4
	marg		**-0.1**
	cv	0.1	0.1

Vegetal materials are *Bt* = FK95 BG2 and Conv = FK37; Descriptive analysis parameters (Desc. Par.) are nb = number of individuals, min = minimum, max = maximum, aver = average, marg = margin, cv=variation coefficient. Var = studied variables.

were significant (p = 0.03) in 2016 and highly significant (p = 0.00) in 2017 and 2018 (Table 4). FK95 BG2 was below FK64 and FK37 by 2.7 and 1.5 mm and by 2.0 and 0.8 mm in 2016 and 2017, respectively, while in 2018 the deficits were 2.7 mm compared to FK64 and 0.6 mm compared to FK37. As regard to strength, FK95 BG2 was below FK37 with 22.5 and 33.3 kN m Kg^{-1} and with 47.0 and 26.5 kN m Kg^{-1} in 2016 and 2017, respectively; in 2018 FK64 outperformed it by 55.7 kN m Kg^{-1} while FK37 was better by 28.2 kN m Kg^{-1}. For the other properties, namely Mic, UI and +b, differences were insignificant both in 2016, 2017 and 2018 years of experimentation

Table 3. Anova of cultivars agronomic characteristics recorded in trials (2016, 2017 and 2018).

Cultivar	Agronomic characteristics														
	FFD[z] (jas)			FBOD (jas)			RDT (kg/ha)			SI (g)			FP (%)		
	2016	2017	2018	2016	2017	2018	2016	2017	2018	2016	2017	2018	2016	2017	2018
FK 37	68.2	74.7	61.3	112.7	121.3	113.7	990.6	581.8	2379.3 a_2	6.8 a_1	4.9	7.7	41.9 a_1	39.5 a_1[y]	42.0 a_1
FK 64	68.2	74.0	61.0	112.2	117.0	113.3	1090.6	524.4	1924.4 a_1	7.6 a_2	5.5	7.8	41.9 a_1	39.9 a_1	42.5 a_2
FK 95 BG2	68.5	73.3	60.3	111.5	117.7	112.0	1150.0	785.9	2389.5 a_2	7.0 a_1	4.6	6.9	43.1 a_2	41.7 a_2	44.6 a_3
Average	68.3	74	60.9	112.2	118.7	113.0	1077.1	630.7	2231.07	7.2	5	7.47	42.3	40.4	43.01
Cv (%)	1.58	1.35	3.51	0.87	1.93	0.98	14.70	24.42	8.36	5.14	11.74	7.33	1.28	1.40	0.29
Probability	0.93 (NS)[x]	0.33 (NS)	0.8 (NS)	0.24 (NS)	0.18 (NS)	0.23 (NS)	0.39 (NS)	0.17 (NS)	0.04 (S)	0.04 (S)	0.30 (NS)	0.19 (NS)	0.02 (S)	0.00 (S)	0.00 (S)
Year*Variable		0.00 (HS)			0.00 (HS)			0.00 (HS)			0.00 (HS)			0.00 (HS)	
Year*Cultivar		1.00 (NS)			0.86 (NS)			0.97 (NS)			0.95 (NS)			0.14 (NS)	

z FFD = first flowering date, FBOD = first boll opening date, RDT = seed cotton yield, SI = Seed Index, LP = lint percent; **y** Means within a column followed by the same letter (a) and index number (a_1 or a_2 or a_3, etc.) are not significantly different according to Scott-Knott test at p = 5% and form a same group. **x** Difference between groups is significant (S) to highly significant (HS). Means with any letter (a) are not significantly different (NS). NS = not significant, S = significant at p = 0.05, HS = high significant at p = 0.01.

Table 4. Anova of studied cultivars major fiber properties analyzed from trials samples (2016, 2017 and 2018).

Cultivar	Fiber properties														
	Mic[z]			UHML (mm)			UI (%)			Str (kN m Kg-1)			+b		
	2016	2017	2018	2016	2017	2018	2016	2017	2018	2016	2017	2018	2016	2017	2018
FK 37	3.3	2.5	4.0	27.6 a_2[y]	26.1 a_2	28.0 a_2	81.1	78.7	80.6	195.0 a_2	232.3 a_2	270.5 a_2	12.5	9.2	8.4
FK 64	3.6	2.8	3.9	28.8 a_3	27.3 a_3	30.1 a_3	81.5	79.4	82.4	283.8 a_2	252.8 a_3	298.0 a_3	13.5	9.4	8.6
FK 95 BG2	3.5	2.3	3.6	26.1 a_1	25.3 a_1	27.4 a_1	80.3	75.97	80.5	261.6 a_1	205.8 a_1	242.3 a_1	12.8	8.8	8.5
Average	3.5	2.5	3.8	27.5	26.2	28.5	81.0	78.0	81.2	280.3	230.3	270.27	13	9.1	8.5
Cv (%)	7.93	9.74	6.23	2.58	0.27	0.96	1.31	2.53	1.37	5.33	3.02	1.76	5.93	6.2	4.5
Probability	0.51 (NS)[x]	0.12 (NS)	0.20 (NS)	0.00 (S)	0.00 (HS)	0.00 (HS)	0.33 (NS)	0.17 (NS)	0.14 (NS)	0.03 (S)	0.00 (HS)	0.00 (HS)	0.22 (NS)	0.41 (NS)	0.77 (NS)
Year*Variable		0.00 (HS)			0.00 (HS)			0.00 (HS)			0.00 (HS)			0.00 (HS)	
Year*Cultivar		0.92 (NS)			0.96 (NS)			0.80 (NS)			0.77 (NS)			1.00 (NS)	

z Mic = micronaire, UHML = upper half mean length, UI = uniformity index, Str = fiber bundle strength, +b = yellow index.
y Means within a column followed by the same letter (a) and index number (a_1 or a_2 or a_3, etc.) are not significantly different according to Scott-Knott test at p = 5% and form a same group.
x Difference between groups is significant (S) to highly significant (HS). Means with any letter (a) are not significantly different (NS). NS = not significant, S = significant at p = 0.05, HS = high significant at p = 0.01.

(Table 4).

DISCUSSION

At least two advantages on agronomic level (insect resistance, FP) for GMC compared to conventional cultivars

Seed cotton yield was an important parameter in our investigation. During 3 years trials, GMC exhibited between 5.44 to 35.1% yield surplus compared to FK64 and FK37, but differences were statistically significantive. In pre-release evaluation prior to adoption, 30% yield gains were expected (Vitale et al., 2008), in addition to four insecticide pulverizings saving as biological efficacy of GMC against main targeted phyllophagous and carpophagous pests (Cabanilla et al., 2005; Omer et al., 2009). However, in real years of cultivation, these gains were adjusted around 15% and then served as baseline of royalties sharing calculation (Vitale et al., 2010).

Transgenes introgressed into Burkina Faso GMC are not specifically yield genes, so observed surplus in yield is a repercussion of their efficacy to control cottons pests, which are harmful in cotton production. According to Monsanto, adoption of *Bt* cotton enhanced yield in Burkina Faso by 17.2% annual average. Moreover, during seven years of production, many growers had become familiar with and faithful to *Bt* technology, then exhibiting production increase, as small as expected combined with reduction in insecticide contact and spraying to be notable assets of GMC (Vitale et al., 2011).

In commercial production, margin between FK95 BG2 and FK37 for FP was positive, to the advantage of GMC. Even better, in trials, it was significantly higher by 1.17 to 2.2% compared to those of FK37 and FK64 in 2016, 2017 and 2018. These results are in agreement with FK37 annual FP averages reported from the ginning tests conducted yearly by SOFITEX and INERA Cotton Research Program that is, 43.19 and 43.77% prior to GMC release, in 2007 and 2008 respectively (INERA, 2007, 2008). During years of GMC production[1], FK95 BG2 and FK37 yielded annual FP averages of 43.16 and 43.12% in 2009, 43.57% versus 42.79% in 2010, 42.79% versus 42.61% in 2011, 43.03% versus 43.51% in 2012, 42.28% versus 42.42% in 2014 and finally 42.24% versus 42.19% in 2015. Taking randomly into account two years of transgenic production and two of no transgenic, it is reported national FP averages of 43.52 and 42.73% in 2013 and 2015, respectively (when the cultivated varieties were FK37 and FK95 BG2) against 42.68 and 42.62% in 2016 and 2017, respectively (when the cultivated varieties became FK37 and FK64) (SOFITEX, 2017). To finish, pre-adoption trials conducted by INERA in 2006 in research stations, reported that FK95 BG2 and FK37 recorded 44.06 versus 43.82% respectively at Farako-Bâ in western cotton belt, and 43.56 against 42.93% at Kouaré in the eastern cotton belt (INERA, 2006).

Assertions that FK95 BG2 had a FP below FK37 by AICB (2015) or Fok (2016) may have been amalgamated; it was FK96 BG2 which presented FP below its conventional near-isogenic Stam59 A as well as FK37, then partly justifying its hasty withdrawal from commercial production by 2013. It is not explainable this advantage of FK95 BG2 in FP to come from the American cultivar donor of transgenes as it is known that Coker 312 is obsolete and below African cotton cultivars for this characteristic (Kuraparthy and Bowman, 2013; Fok, 2016). The recovery of agronomic characteristics, like FP, being easier around 3 back-crosses (Stiller et al., 2006), a hypothesis of a recovery obtained by BC2 can be issued if it was not beyond the expected value of FK37. More likely hypothesis is beneficial random recombinations of genes caused by crossings or backcrossings, transgressive segregation, or heterotic effect but the latter is not usual in cotton (Shankar et al., 2018), even depressive effect for FP after hybridization is reported (Mendez-Natera et al., 2007).

FP is an intrinsic characteristic of African cotton cultivars, especially in French-speaking countries, expressing the highest level in the world (Mergeai, 2006; Dessauw and Hau, 2007; Fok, 2016). In the case of Burkina Faso GMC, this advantage in FP conferred by the transgenic conversion process has not been sufficiently highlighted or sufficiently exploited to its true value; maybe because it was coupled with a major fiber handicaps, reduced length and strength, which resulted in at least temporary rejection of the entire GMC technology.

A major fiber length disability played a critical role in stopping GMC commercial production in Burkina Faso

Results of our investigation showed net significant differences between GMC and FK37 then FK64 as regard to fiber properties that is, length and strength, in trials as well as in commercial production. These results are in the same trends to those reported by the cotton comapanies grading office during years of commercial cultivation, from 2009 to 2015. According to these data, there were no significant differences between GMC and FK37 for Mat, Mic, Ui, Elo, +b, Sfi and Rd; these characteristics are known to be more influenced by production conditions than by cultivar (Darawsheh, 2010). For UHML and Str, the differences between compared materials are considered consistent. As exemples,

[1]INERA-SOFITEX ginning tests are conducted annualy in order to keep ginners in good conditions. Results reported here were based on tests on FK95 BG2 vs. FK37 i.e. 32 vs. 22 in 2010; 46 vs. 19 in 2011; 49 vs.27 in 2012; 45 vs. 31 in 2013; 54 vs. 23 in 2014; 36 vs.19 in 2015.

analysing 6,875 fiber samples[3] from FK95 BG2 and 5,821 fiber samples from FK37, the following differences appeared between the two varieties, respectiveley, in 2012: 4.26 vs. 4.07 for Mic, 80.16 vs. 80.93% for Ui, 84 vs. 84% in Mat, 11.14 vs. 10.02 in Sfi, 8.85 vs. 7.99 in Elo, 78.34 vs. 77.83 in Rd, 9.30 vs. 9.27 in +b, 26.74 mm vs. 28.25 mm in UHML and 270.77 kN m Kg^{-1} vs. 290.47 kN m Kg^{-1} in Str. In the last year of GMC cultivation in 2015, from analysis based on 3,263 FK95 BG2 fiber samples and 1,615 FK37 fiber samples, it appeared the following differences: Mic (4.37 vs. 4.17), Ui (79.82 vs. 80.51%), Mat (87 vs. 87%), Sfi (10.06 vs. 9.52), Elo (5.35 vs. 4.75), Rd (79.19 vs. 78.82), +b (9.05 vs 9.06), UHML (27.40 vs 28.65 mm) and Str (289.00 vs. 308.60 kN m Kg^{-1}). In other words, comparing two years of transgenic production and two year of no transgenic, it is reported that 54.45 and 51.75% of all entire cotton fiber were sold as ordinary short staple (1.1/16" to 1.3/32") in 2014 and 2015, respectively. After GMC withdrawal, Burkina Faso cotton fiber was already marketed in superior short staple classification (1.1/8" to 1.7/32") at 99.2 % by 2017 and 93.25 % in 2019 with FK37 and FK64 as commercially cultivars (AICB, 2019).

All the aggregate results clarify and abound in the sense of no complete equivalence between FK95 BG2 and FK37 for certain fiber properties, UHML and Str, at the origin of dissatisfaction of the cotton sector and which led to suspension of GMC in Burkina Faso (AICB, 2015). Diference is very presumably genetic effect and was already suspected during the first pre-release experiments in 2006 at Faroko-Bâ and Kouaré; it was showed that FK95 BG2 (or FK37 BGII) fibers were shorter and less tenacious than those of FK37. As FK96 BG2 (Stam 59A BGII) is concerned, in addition to handicaps in fiber length and strength, its ginning turn-out (FP) was lower compared to Stam 59A from which it is derived (INERA, 2006). At this time, used GM seeds were judged as low-end (BC2), sent only for biological effectiveness demonstration purposes. Higher-performing, more advanced backcrossing seeds expressing all expected *Bt* transgenes and all qualities found in conventional cultivar were promised to Burkina Faso as soon as an agreement is signed for large-scale production (D. Sanfo, INERA, personal communication).

The commercial production was launched in 2009 with FK95 BG2 and FK96 BG2, however and more likely, the same low-end BC2 seeds. By 2010, problems in fiber length were highlighted on all GMC cultivars in large-scale production by the cotton companies. According to Monsanto, these shortcomings are related to the growing conditions of Burkina Faso, arguing that Cooke et al., (2001) reported that any variation in characteristics between GMC and their conventional isogenics is most often attributable to environmental factors and production conditions. On the international fiber market, the reputation of Burkina Faso for providing high quality cotton is negatively affected; cotton from Burkina Faso was even discounted on shorter fibers from *Bt* cotton and a penalty was promulgated on all export sales of cotton produced from 2010 (Fok, 2016). During a tripartite consultation (AICB-INERA-MONSANTO) in 2011, INERA reasserted that GMC fiber handicaps in length and strength are more of varietal origin than environmental effect, suggesting advancement of backcrosses in hope to solve the problem. Monsanto agreed and assumed an obligation to provide more advanced back-crossed GMC cultivars by 2014 (D. Sanfo, INERA, personal communication).

[3]SOFITEX grading office data. Data are from a compilation individual FK95 BG2 and FK37 bales fiber analysis grading by HVI

Bt transgenes (Cry1Ac and Cry2Ab) have been introgressed in local cultivar to create the GMC, but imperfectly

In the GMC path, similar to Australia, Burkina Faso wanted to take into account the specificity of its varieties, well adapted to local conditions with good yield and meeting fiber market requirements (Constable et al., 2001; ICAC, 2013). Because direct transgenic introgression is tedious and expensive (May et al., 2003), crossing route with the already easily transformed Coker 312 variety was used to obtain Burkina Faso *Bt* cultivars. It seems that the donor parent was inappropriate as Kuraparthy and Bowman (2013) reported Coker 312 to be an old and obsolete variety, out of commercial production in USA since a couple years. Its fiber properties are far different i.e. shorter at least two millimeters and lower in FP compared to French-speaking African countries' varieties (Kuraparthy and Bowman, 2013; Fok, 2016). By stopping the backcross process at two only (BC2), the genetic background of Burkina Faso GMC was theoretically composed of 87.5% from local cultivars genetic value versus 12.5% from American donor cultivar; this amount of remaining undesired genetic background from Coker 312 was high enough to affect the quality of converted varieties. An advancement of the backcrossing process up to BC6, to raise GMC cultivars' genetic background to 99.22% of genetic value from local cultivars, could have drastically reduced probability of undesirable Coker 312 trait effects. However, Stiller et al. (2006) pointed out difficulty even impossibility of recovering all desired characteristics in a transgenic conversion process in cotton. According to these authors, at most 3 backcrosses can recover major agronomic traits, and for any other trait, 3 to 5 backcrosses followed by a rigorous selection should be sufficient.

In 2011, during a tripartite consultation (AICB-INERA-MONSANTO), Monsanto endorsed the idea to continue the backcross process but for work that could have been done on site, the process (backcrosses and selections) were conducted outside Burkina Faso. Since 2012, eight cotton lines called BC3 hastily developed have been delivered to AICB. After 3 years of trials evaluation on dozens of sites conducted by INERA, no new line was found combining more both agronomic and technological achievements of FK37, being able to substitute FK95 BG2 (Bourgou et al., 2014).

Conclusion

The present study comparing FK95 BG2, FK37 and FK64 highlights a genetic effect on differences between GMC and conventional; production condition, year or site would be non-significant. Indeed, GMC presented equivalences with the conventional cotton for certain agronomic characteristics and fiber properties. It even had some asset, sometimes significant compared to conventional cultivars, especially FP and seed cotton yield to a lesser extent (not significant). But GMC was carrying major handicaps in fiber length and strength, pointed out in trials as well as in large-scale production. Although conversion was not focused on fiber properties, entire recovery in fiber length and strength was crucial as these characteristics are, like FP, intrinsically linked to African cotton cultivars. They are also reflecting the reputation of countries on the fiber market, so difference in fiber lengh was an important shortcoming, which led to GMC withdrawal.

Problems observed in Burkina Faso GMC were, more likely, a consequence of imperfect conversion caused by certain precipitation and lack of rigor in the process conducted outside Burkina Faso. It was a great opportunity for Burkina Faso to benefit GMC of introgressed local cultivars as adoption of non-local transgenic cultivars could result in unsuitability to local production conditions. However, it should be of more advanced (at least 6) backcrossing level and paired with an effective selection process to recover as much as possible very specific characteristics linked to varieties from which they are made. Rigorous selection after backcrossing is critical when traits differ signficantly between donor and recurrent parent. The revocation of GMC means a return back to conventional cultivation and FK64 a new launching variety confirmed potentials. But, taking into account all known benefits demonstrated by GMC in Burkina Faso and elsewhere, and the increasing parasitic pressures, temptation of Burkina Faso to return back into GMC is high.So, the following recommendations must be made and rigorously followed to ensure irreproachable quality of conversion process and transformed cultivars to be used:

(i) Always develop GMC via local cultivars, already adapted to local production conditions, expressing regional or even national specificities in terms of cotton sector requirements and good fiber quality for fiber market;
(ii) Run on the national territory the entire process to develop local transgenic cultivars, by fully empowering national breeders, especially if the introgression is by crossing. This approch allows continuous adaptation of materials in creation to local conditions;
(iii) Carry out pre-release tests on GMC biological efficacy and also a special focus on conversion effects on agronomic characteristics as well as fiber properties, in research stations and in large-scale commercial production environments.

These recommendations are effective for any other country attempted by GMC adventure.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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