Potential Genetic Benefits of Using Brazilian Cotton Varieties to Improve those Cultivated in the C4 Countries: 1. Analysis of Major Architectural and Agronomic Characteristics

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Summary

The study compared the adaptability of cotton varieties from Brazil and C4 countries (Benin, Burkina Faso, Mali and Chad) to cultivation conditions in Burkina Faso. A Fisher experimental block design was used at two sites during 2010 and 2011. Major agronomic and architectural characteristics were selected, which can be used to describe the production setting up, precocity and yield performances of the varieties. The results revealed that Brazilian varieties produced significantly fewer branches (NVB and NFB) and fruiting sites (SVB and SFB), but produced more bolls (BFB) compared to A 51 (Chad) and STAM 59A (control). At agronomic level, almost all Brazilian varieties seemed to show a lower fiber percent. BRS 293 and, to a lesser extent, CEDRO were found to be the best all-round Brazilian varieties, as they produce a similar fiber percent to the best African varieties, as well as a better potential cottonseed yield (BRS 293) and large boll production (CEDRO) compared to African varieties. It will be possible and easy to use some Brazilian varieties in crossings, in order to enhance African varieties, and technical analysis should make it possible to identify the appropriate varieties.

Résumé

Apports génétiques potentiels de variétés de cotonniers du Brésil à l'amélioration des variétés de cotonniers cultivés des pays du C4 : 1. Analyse des caractéristiques architecturales et agronomiques majeures

L'étude a comparé l'adaptabilité de variétés du Brésil et des pays du C4 (Bénin, Burkina Faso, Mali, Tchad) dans les conditions de culture du Burkina Faso. Elle a été conduite dans un dispositif en Bloc de Fischer en 2010 et 2011 sur 2 sites. Des caractéristiques architecturales et agronomiques majeures qui permettaient de décrire la mise en place de la production, les performances en termes de précocité et de rendement des variétés ont été utilisées. Les résultats ont révélé que des variétés brésiliennes présentaient, significativement, moins de branches (NBV et NBF), moins de sites fructifères (SBV et SBF) mais plus de capsules (CBF) par rapport à A 51 (Tchad) et STAM 59A (témoin). Au plan agronomique, les variétés du Brésil semblaient toutes faibles en rendement fibre. BRS 293 et dans une moindre mesure CEDRO se sont montrées plus complètes combinant un rendement en fibre similaire aux meilleures variétés africaines et un potentiel en rendement coton graine (BRS 293) et en PMC (CEDRO) meilleur que ces dernières. Des possibilités pratiques de valorisation des variétés brésiliennes comme géniteurs existent et les analyses de la technologie de la fibre devraient mieux les situer.

Introduction

In French-speaking West Africa, cotton growing was controversial in the past, but remains one of the few success stories after independence. In ancient times, it was practised in order to meet domestic needs. Over the years, cotton has emerged as a real tool for combating poverty and improving living conditions for rural populations. Its positive impacts are well documented (6, 16).

At microeconomic level, the development of cotton production has been correlated with increased income for approx. Two million families and 16 million people in rural areas. In addition, the cotton sector contributes greatly to the creation of employment and basic social services (16). At macroeconomic level, fibre exports generate a large volume of revenue for the national economies of many West African countries, in taxes and other forms of income. This income is of strategic importance for economic stability and investment in development in the broadest sense (2, 7, 12).

Despite its high dependence and being ranked as the world's second largest exporter in 2004-2005, Zone Franc Africa has not managed to profit fully from the cotton that it produces, despite it being of above-average quality (7). The competitiveness of African cotton has been put to the test on the international

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market and this has threatened the existence of sectors and especially growers (12). At the 2003 World Trade Organisation (WTO) conference in Cancun, cotton subsidies from northern hemisphere countries (USA, China, EU, etc.) were officially denounced by Africa's cotton 4 initiative (C4) countries and Brazil. In addition to subsidies and the volatility of world prices, more detailed diagnostics highlight problems linked to productivity in the field, fiber conversion and diversification of cotton companies' activities (2, 5, 7). We consider that the competiveness of African cotton can be improved, even to a small extent, by increasing yields, which have been below the world average since the early 1990's (2, 16). The development and dissemination of improved varieties remains one of the main way for improving productivity, especially if resources are available for genetic improvement (10). During the discussion between cotton breeders initiated by the West African Economic and Monetary Union (WAEMU), it emerged that the gene pool is almost identical in Benin, Burkina Faso, Mali and Chad (C4 countries). It is also aging and increasingly degenerated to face the current breeding challenges (11), as it was no longer fed after the IRCT (Research Institute of exotic cotton and textile) stopped its activities in Africa (Fok M., comm. pers.). In 2009, as part of a South-South cooperation, Brazil provides the C4 countries with *Gossypium hirsutum* L. varieties, which could be rebreeded or used as parent plants after being evaluated. For this reason, a collaborative trial was conducted in each of the C4 countries during 2010-2011, with the aim of comparing Brazilian varieties with those from the C4 countries. The objective was to provide evidence of genetic variability within the varieties introduced. This article summarises and analyses the results obtained by the trial under cotton growing conditions in Burkina Faso.

1. Materials and methods

Plant material

The plant material consisted of 5 Brazilian varieties (ARACA, BRS 286, BRS 293, CEDRO, BURITI) and a native variety from each of the C4 countries, Benin (H279-1, rebreeding of STAM F: [(SR1F4 * L299.10) * (Stoneville 213) * (G115-7)^3] * [(T120-7 * U585-12) * (T120-7 * P279)]), Burkina Faso (FK37: H^{2}784 * IRMA BLT/PF), Mali (N'TAL 100: N'TA 88-6 * STAM 59A) and Chad (A 51: {[(MK 73 * L231-24) * ((DPMA * HAR 48-6) * Y1422)] * [STAM F]} -1697-Z563-157-A 51). A Togolese variety, STAM 59A: [(SR1F4 * L299-10) * (Stoneville 213) * {G115-7}3] * [(T120-7 * U585-12) * (T120-7 * P279)] was used as a control. All these varieties belong to the cultivated species *G. hirsutum*.

Study sites

The study was conducted in 2010 at Farako-Ba (longitude 4°20' West, latitude 11°06' North, altitude 405 m) and in 2011 at Farako-Ba and Kouare (longitude 0°19' East, latitude 11°59' North, altitude 850 m). The climate is generally more arid in Kouare than in Farako-Ba. The cumulative rainfall in Farako-Ba was 1289.5 mm for 79 days of rain (2010) and 831.5 mm for 73 days (2011). In 2011, Kouare recorded 669.2 mm in 30 days of rain. In general, the soils at the 2 sites are ferasols (FAO classification), low clay and organic matter content. They are sandy loam in texture, slightly acidic and deficient in Nitrogen and Phosphorus (1).

Experimental design and conduct of experiment

A Fisher block design with 4 replications was used. The elementary plot (EP) for each replication consisted of 3 x 20 m lines spaced 0.8 m apart. The distance between seeding holes was 0.40 m. In the first year, at Farako-Bâ, the soil was amended with manure (6 t/ha) during ploughing. At the two sites, NPKSB (14-18-18-6-1) at 150 kg/ha and urea (46% N) at 50 kg/ha were applied each year, 20 and 45 days after sowing (das), respectively. Avaunt 150 EC (Indoxacarb 150 g/L), followed by Lambdacal P 636 EC (Zetamethrin 36 g/L + Profenofos 600 g/L) and Conquest C176 EC (Cypermethrin 144 g/l + Acetamiprid 32 g/l) were used in 6 treatments every 2 weeks. The treatments began 30 das at doses of 0.17, 0.334 and 0.25 litre/ha, respectively, per insecticide. Two manual weeding were conducted at 15 das (at thinning out) and at 45 das (weeding and ridging).

Measuring variables

The agronomic variables were measured along the central line of each PE in 2010 and 2011 at Farako-Ba: the first flowering date (FFD)/first boll opening date (FBOD), the date by which 50% of the plants produced at least one flower/one open boll; the cotton seed yield (YLD) deducted using the total harvest; the average boll weight (ABW) calculated from all the bolls from 20 plants; the fiber percent (FP) measured after ginning of 200 g cotton seed; the seed index (SI) or average weight of 5 samples of 100 undelinted seeds.

The morphological variables were measured on 20 plants from the central line of each EP at Farako-Ba and Kouare, according to the "plant mapping" method (3). The variables were the insertion node of the first fruiting branch (INFB), the number of vegetative (NVB) and fruiting (NFB) branches, the number of bolls produced on vegetative (BVB) and fruiting branches (BFB), the number of sites on vegetative branches (SVB) and fruiting branches (SFB), the number of nodes on the main stem (NN) and plant height in metres (PH).

Data analysis

The data collected was subjected to a variance analysis (ANOVA) using SISVAR 5.1 Build 72 software. The averages for each variety were compared using the Scott-Knott test, based on a 5% threshold.

2. Results

Architectural characteristics

The variance analyses conducted on the architectural variables do not reveal any significant differences between the varieties at Kouare (results not provided).

Table 1
Classification of varieties after ANOVA for morphological variables (Farako-Ba)

Varieties	Variables measured								
	INFB	NVB	BVB	SVB	NFB	BFB	SFB	NN	PH
ARACA	5.00 a_2	2.70 a_2	3.82 a_2	11.30 a_2	10.42 a_2	11.50 a_2	17.95 a_1	16.97 a_2	96.87 a_1
BRS 286	4.72 a_1	2.87 a_2	5.82 a_2	14.27 a_3	11.40 a_3	13.52 a_2	21.07 a_2	17.42 a_2	100.75 a_1
BRS 293	5.05 a_2	2.75 a_2	4.42 a_2	12.45 a_3	10.97 a_3	12.20 a_2	20.92 a_2	17.57 a_2	104.67 a_1
BURITI	5.25 a_2	2.70 a_2	3.60 a_2	10.60 a_2	10.47 a_2	11.70 a_2	16.90 a_1	17.10 a_2	103.87 a_1
CEDRO	4.57 a_1	2.07 a_1	1.12 a_1	6.85 a_1	9.42 a_1	9.80 a_1	16.52 a_1	15.92 a_1	118.92 a_2
STAM 59A	5.65 a_3	3.05 a_2	4.55 a_2	14.32 a_3	11.85 a_3	10.72 a_1	19.22 a_2	19.12 a_4	111.60 a_2
A 51	6.22 a_4	3.20 a_2	3.55 a_2	15.12 a_3	11.47 a_3	9.20 a_1	20.25 a_2	19.70 a_4	110.82 a_2
FK37	5.4 a_3	2.42 a_1	3.50 a_2	10.70 a_2	11.40 a_3	10.57 a_1	19.67 a_2	18.20 a_3	109.37 a_2
H279-1	4.65 a_1	1.90 a_1	1.67 a_1	7.97 a_1	11.07 a_3	10.57 a_1	20.60 a_2	18.22 a_3	104.75 a_1
N'TAL 100	4.87 a_2	2.20 a_1	2.00 a_1	9.00 a_1	10.37 a_2	9.07 a_1	15.70 a_1	16.82 a_2	115.82 a_2
Average	5.14	2.59	3.41	11.26	10.89	10.89	12.95	17.71	107.75
CV (%)	5.01	11..66	36.84	19.91	4.92	11.63	18.88	3.67	6.95
Probability	0.0000 HS	0.0000 HS	0.0004 S	0.0000 HS	0.0000 HS	0.0007 S	0.0263 S	0.0000 HS	0.0075 S

At Farako-Ba, however, the varieties studied showed significant to highly significant differences for all the observed variables (Table 1).

The average number of nodes of insertion of the first fruiting branch (INFB) is 5.14 nodes. All the Brazilian varieties presented a fairly low INFB. CEDRO and BRS 286 from Brazil (4.57 and 4.72 nodes, respectively) and H279-1 from Benin (4.65 nodes) have the lowest INFB, whereas the number for A 51 from Chad (6.22 nodes) is the highest (p= 0.0000). The INFB of the regional control STAM 59A was 5.65 nodes.

The parameters for vegetative branches (NVB, SVB and BVB) indicate that the African varieties H279-1, N'TAL 100, FK37 and Brazilian variety CEDRO significantly produced the lowest number of vegetative branches (p= 0,0000). The same varieties (except for FK37) produced, significantly, the fewest sites and bolls on these branches; the average amounts produced were 11.26 sites and 3.41 bolls, respectively. The African varieties (A 51 and STAM 59A) and those from Brazil, especially BRS 286, BRS 293, produced more vegetative branches, sites on vegetative branches and bolls than all the other varieties. The ARACA and BURITI varieties presented an intermediate behaviour for all these parameters.

With regard to parameters associated with the fruiting branches, the average number of fruiting branches (NFB), sites on fruiting branches (SFB) and bolls on these branches (BFB) were 10.89 branches, 12.95 sites and 10.89 bolls, respectively. All the African varieties, except for N'TAL 100, produced the most fruiting branches, together with varieties BRS 286 and

Table 2
Classification of varieties after ANOVA for agronomic variables (2010)

Varieties	Variables measured					
	FFD (das)	FBOD (das)	YLD (kg/ha)	FP (%)	ABW (g)	SI (g)
ARACA	65.00 a_2	114.00 a_2	1015.66 a_3	39.67 a_1	4.55 a_1	8.33 a_1
BRS 286	65.50 a_2	113.50 a_2	824.83 a_2	41.08 a_2	4.51 a_1	8.46 a_1
BRS 293	68.50 a_3	116.00 a_2	947.10 a_3	42.16 a_3	5.08 a_2	8.82 a_2
BURITI	69.75 a_3	115.75 a_2	748.90 a_2	39.54 a_1	5.18 a_2	8.92 a_2
CEDRO	65.00 a_2	114.75 a_2	1023.30 a_3	40.87 a_2	5.76a_2	8.70 a_2
STAM 59A	61.75 a_1	111.50 a_1	953.95 a_3	42.86 a_3	4.39 a_1	8.21 a_1
A 51	67.00 a_3	112.00 a_1	502.40 a_1	41.49 a_2	4.32 a_1	8.08 a_1
FK37	63.00 a_1	110.50 a_1	1229.73 a_3	42.69 a_3	4.86 a_1	8.49 a_1
H279-1	63.25 a_1	111.50 a_1	1172.54 a_3	43.25 a_4	4.95 a_1	8.42 a_1
N'TAL 100	64.75 a_2	112.50 a_1	853.84 a_2	43.46 a_4	5.61 a_2	8.32 a_1
Average	65.35	113.20	927.23	41.71	4.92	8.47
CV (%)	2.30	1.31	20.58	1.35	9.80	2.93
Probability	0.0000 HS	0.0001 S	0.0006 S	0.0000 HS	0.0016 S	0.0009 S

Table 3
Classification of varieties after ANOVA for agronomic variables (2011)

Varieties	Variables measured					
	FFD (das)	FBOD (das)	YLD (kg/ha)	FP (%)	ABW (g)	SI (g)
ARACA	62.00 a_3	108.75	1896.87 a_2	41.57 a_1	5.19 a_1	8.12
BRS 286	61.00 a_3	105.25	2045.31 a_2	42.72 a_1	5.21 a_1	8.06
BRS 293	60.25 a_2	108.00	2423.44 a_2	44.08 a_2	5.83 a_2	8.32
BURITI	63.00 a_3	108.50	2159.37 a_2	42.55 a_1	5.34 a_1	8.67
CEDRO	61.25 a_3	106.50	1917.19 a_2	44.08 a_2	5.76 a_2	8.43
STAM 59A	61.00 a_3	108.00	2043.75 a_2	44.76 a_2	5.61 a_2	8.11
A 51	64.00 a_3	108.50	1642.19 a_1	42.56 a_1	4.95 a_1	8.41
FK37	60.00 a_2	105.00	2228.12 a_2	44.79 a_2	5.31 a_1	8.42
H279-1	57.50 a_1	106.50	2253.12 a_2	45.37 a_2	5.20 a_1	8.24
N'TAL 100	62.00 a_3	108.25	1975.00 a_2	47.09 a_3	5.24 a_1	7.87
Average	61.20	107.32	2058.44	43.96	5.36	8.26
CV (%)	2.63	1.96	13.37	1.67	5.95	5.16
Probability	0.0006 S	0.1220 NS	0.0283 S	0.0000 HS	0.0115 S	0.3412 NS

BRS 293. The Brazilian varieties CEDRO and, to a lesser extent, ARACA and BURITI produced the lowest number of branches. These three varieties, as well as N'TAL 100, also produced the lowest number of sites on these branches (p= 0.0263). Finally, all the Brazilian varieties (except CEDRO) retained significantly more bolls on their fruiting sites on these branches than all the African varieties (p= 0.0007).

Finally, the average plant height and number of nodes on the varieties studied were 107.75 cm and 17.71 nodes, respectively. The Brazilian varieties ARACA, BRS 286, BRS 293 and BURITI, as well as H279-1, produced the shortest plants (p= 0.0075). CEDRO, though one of the shortest varieties, produced the lowest number of nodes (15.92 nodes). The control STAM 59A and A 51 produced the highest numbers of nodes (19.12 and 19.70 nodes, respectively).

Agronomic characteristics

The variance analyses conducted on agronomic variables indicate significant differences between the varieties for all the variables analysed in 2010 (Table 2). In 2011, the differences remained significant for most of the variables, whereas the first boll opening date (FBOD) and seed index (SI) appeared non-significant (Table 3).

The average first flowering and first boll opening times in 2010 were 65.35 and 113.20 das, respectively, compared to 61.20 and 107.32 das in 2011. In 2010, as in 2011, the varieties H279-1 and FK37 flowered earlier, while the varieties A 51 and BURITI still flowered later. The majority of Brazilian varieties showed an intermediate tendency. In 2010, all the African varieties opened their first boll earlier than the Brazilian varieties (p= 0.0001), whereas in 2011 the analyses no longer revealed any significant differences between the varieties studied (p= 0.1220).

In terms of yield (YLD), in 2010, the varieties could significantly be divided into 3 groups (p= 0.0006). FK37, H279-1 and the Brazilian varieties BRS 293, ARACA were statistically similar and the most productive with over one tonne per hectare. The other varieties produced less than 1 t/ha and A 51 (502.40 kg/ha) was statistically the least productive. In 2011, all the varieties were more productive, with yields of over 2 t/ha for most varieties. Some varieties more than doubled (N'TAL100, BURITI) or even tripled (A 51) their yield. The variety A 51 remained significantly the least productive, while all the other varieties appeared to be similar (p= 0.0283).

In terms of fibre yield after ginning, the varieties can be divided, highly significantly, into 4 groups (2010) and 3 groups (2011). Over the 2 years, the varieties N'TAL 100 (43.46 and 47.09%) followed by H279-1 (43.25 and 45.37%) were the most yielding, based on this parameter (p= 0.0000). The varieties FK37, STAM 59A, BRS 293 and CEDRO have always been statistically similar and intermediate. The varieties ARACA (39.54 and 41.57%) and BURITI (39.67 and 42.55%) and, to a lesser extent, BRS 286 (41.08 and 42.72%) and A 51 (41.40 and 42.56%) produced the lowest fiber percent after ginning in 2010 and 2011.

In terms of average boll weight (ABW), BURITI and BRS 293 performed consistently better over the two years. In 2010, the varieties CEDRO (5.76 g), N'TAL 100 (5.61 g), BURITI (5.18 g) and BRS 293 (5.08 g) produced the highest ABW, whereas in 2011, BRS 293 (5.83 g), BURITI (5.76 g) and STAM 59A (5.61 g) performed the best; the remaining varieties being similar and producing statistically smaller bolls.

Finally, in terms of seed index (SI), the Brazilian varieties with large bolls (BURITI, BRS 293 and CERDO) were statistically the most interesting in 2010 (p= 0.0009). In 2011, the varieties did not present any significant differences for this variable (p= 0.3412).

3. Discussion

According to the results on architectural and agronomic characteristics, the evaluated varieties behaved differently, depending on the year and site.

When it comes to cotton plants, the evaluation of architectural parameters points out crop production setting up and allows to predict the yield. In this study, the varieties from Brazil and the C4 countries did not present significant differences at Kouare for these parameters. This result could be explained by the late start and sudden end of the rainy season at this site in 2011. These conditions might actually have produced a similar effect to late sowing, as it disallowed the varieties to show their architectural potential and to grow differently (14). The results from Farako-Ba, which showed architectural differences between the varieties studied, are in line with those produced by previous evaluations of varieties introduced for research purposes as gene sources from Argentine, the USA, Nicaragua, Costa Rica, Uzbekistan, Israel and Australia (13, 15). In general, the African varieties were more height and more vegetative than the varieties introduced. In our study and in general, the Brazilian varieties were similar to their African counterparts in terms of production of fruiting branches and sites. However, the Brazilian varieties produced more bolls on their fruiting sites, which presented a good retention rate, probably due to higher tolerance to biotic and abiotic stresses. These varieties may provide a solution in the search for varieties or cultivation conditions that promote good boll retention on the plant, which is a key objective for cotton research (14). Moreover, under the conditions at Farako-Ba, some of the Brazilian varieties could be used for crossings, if required, in order to reduce the number of vegetative branches, total plant height and increase boll production on fruiting branches in some varieties in the C4 countries; especially as these characteristics are highly to moderately heritable (8). This type of investigation will be particularly interesting and effective for the Chadian variety (A 51) and regional control (STAM 59A), which were proved less enhanced than most of the Brazilian varieties regarding these parameters.

In 2011, all the varieties studied tended to improve in agronomic terms compared to 2010. They were able to take advantage of the delayed beneficial effect of organic fertiliser and benefit from an exceptionally well watered location, with regular rainfall at the site in Farako-Ba. Despite everything, the Brazilian varieties produced lower cotton seed yields than their potentials under the cotton growing conditions in Brazil (4, 9). In terms of general agronomic performances, the Brazilian varieties also behaved equally or better than the regional control, and especially the Chadian variety. However, only BRS 293 and, to a lesser extent, CEDRO and BURITI appeared as complete as the local variety (FK37) and the varieties popularised in Benin (H279-1) and Mali (N'TAL 100). The other Brazilian varieties were characterised particularly by an average fiber yield after ginning of under 42%. Even under the conditions in Brazil, their fibre yield fell between 38-40% (4). This varietal characteristic is highly heritable (heritability> 0.5) (10) and particularly valued in the C4 countries. The first requirement, if a new variety is to be accepted and become popular, is that it exceeds a minimum threshold of 42% in Burkina Faso and 44% in Mali. In fact, this varietal characteristic remains one of the traditional methods of increasing fiber production in these countries (10). In Brazil, unlike the C4 countries, cotton is produced mainly on large areas, so that any failure to increase fibre yield after ginning can be compensated by very good yields in the fields and large cotton seed yields.

Conclusion

If improved and stable varieties are to be developed, which are well suited to the cultivation conditions, it will be needed to achieve breeding resources with good knowledge of their wide genetic variability or diversity. Genetic resources for cotton plants that were shared as part of the C4 project were evaluated in this study. Overall, we have determined that the varieties compared differ slightly. The Brazilian varieties are less interesting in terms of fiber percent but present an attractive yield potential in the field. Some of the varieties have shown attractive characteristics, ranging from slightly (YLD, ABW) to very slightly heritable (number of bolls), which can be used for crossings in order to improve, in particular, the Chad variety and the regional control, as these two varieties have under-performed in all areas. Though undermined by our production techniques, the variety BRS 293 proved a fairly good all-rounder and as productive as the varieties currently popularised in Burkina Faso (FK37), Mali (N'TAL 100) and Benin (H279-1).

In order to identify more accurately the advantages to be gained from these Brazilian varieties, it would be possible to determine the intensification level, for which they appear best suited. These genetic resources derived from the Brazilian and African varieties are already being considered for the creation of new varieties using genealogical selection. However, as fibre is the main product, it is vital that we study the fibre technology, which will be more helpful information when considering the different varieties.

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