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BREEDING AND GENETICS

Characterizing Primitive Cotton Acccessions (*Gossypium* spp.) Collected in Burkina Faso to Identify Potential Sources for Fiber Quality Enhancement in West African Cultivars

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ABSTRACT

African cotton cultivars produce consistent fiber quality. However, they are far from perfect as they are old, with fiber quality lagging compared to modern cotton cultivars produced in competing countries. This study compared cotton accessions collected across Burkina Faso belonging to the four cultivated species to cultivars from West African countries (Benin, Burkina Faso, Mali, and Togo) plus Chad. The objectives were to quantify the fiber quality components within the collection and to identify accessions with the potential to enhance the fiber quality of African cultivars to address evolving markets and environments. In terms of lint percent, accession E32 (*G. hirsutum*) outperformed all cultivars by 2.5 to 4.6%. Accessions E25, E1, and E12 (all *G. barbadense*), and E53 (*G. hirsutum*) produced fibers 1.7 to 4.6 mm longer than the control cultivars, except for cultivar FK37. All *G. hirsutum*, *G. barbadense*, and *G. herbaceum* accessions had longer fibers than all control cultivars. Some *G. hirsutum* accessions with perennial tendency, averged 3.5 to 5.5% greater elongation. For fiber strength, all *G. barbadense* accessions appeared better than comparision cultivars and E13, E38 (*G. arboreum*), and E43 (*G. herbaceum*) produced fibers with bundle strength values from 7.3 to 10.2 kN m Kg^{-1} greater than any comparision cultivar. Further enhancement of certain African cotton fiber properties could be possible through a research-based breeding program to identify and use current variability found in African accessions as well as other accessions.

Africa is an ancient home of the cultivated diploid species of *Gossypium*. It is reported that *G. arboreum* L. and *G. herbaceum* L., both of genome A, were domesticated at least 7,000 years ago in the Indus Valley and in southeastern African coastal regions, respectively. These ancient cotton phenotypes that produce spinable fibers were dispersed mainly by Arab traders. Then, these cottons became largely cultivated in India, Africa, and southeast asian countries (Hutchinson, 1949; Wendel et al., 2010).

More recently (16th century and after), the triangular trade and industrial cultivation led to introductions from the Americas to coastal regions of West Africa of *G. barbadense* L. cottons and, more importantly, those of *G. hirsutum* L. At least three races of *G.barbadense*: *vitifolium*, *peruvianum*, and *brasiliense* and three of the seven perennial races of *G. hirsutum*, namely *punctatum*, *marie-galante*, and *latifolium*, were widely distributed across Africa (Hau, 1996; Hutchinson, 1949).

The adoption of industrial cotton cultivation in Africa effectively started during the colonial period (1895-1960). Initial importation and adaption of improved cultivars bred in the U.S. and introduced into Africa was short-lived, most likely because these cultivars were not well adapted to African growing conditions (Hau, 1996). Later, from 1950 to 1980, significant adaptation research efforts by the African cotton network (Ivory Coast, Central African Republic, Chad, Togo, Mali, Cameroon, Madagascar, Senegal, and Burkina Faso) under the leadership of the Research Institute on Cotton and Exotic Textiles (IRCT) resulted in adapted cultivars for Africa. More than 90 successful cultivars were bred and popularized in many African countries as summarized by Hau (1996). From 1960 to 1985 on-farm yield jumped from 100 to 400 kg fiber ha^{-1}, while gin turnout improved from 38 to 44 % and the primary fiber quality

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properties were improved to global competitive levels (Berti et al., 2006; Lançon et al., 1990).

Cotton is an important agricultural commodity in many African countries. Producers are essentially small holders farming in rainfed conditions, with a low to medium level of technical intensification. Approximately 16 million people in West and Central Africa draw benefits—directly or indirectly—from cotton, which accounts for 25 to 50% of the total foreign exchange earnings and contributes approximately 3 to 10% to gross domestic products (Hussein et al., 2005).

However, industrial cultivation and early and modern improvement efforts have narrowed the genetic base of cultivated cottons. Intensive selection imposed to realize "the ideal ideotype" that maximizes yield and adaptation, and selection for early maturity has resulted in homogenization among current cultivars and eliminated substantial variation within elite *G. hirsutum* germplasm pools (Lançon et al., 1990; May, 2003). Cotton breeding resources in African countries of Benin, Burkina Faso, Mali, Togo and Chad are genetically similar (Bourgou and Sanfo, 2012). Lack of diversity in an ageing germplasm base increases difficulty of addressing current breeding challenges in Africa.

Landrace, dooryard, or commensal cottons, because of extensive adaptability and good resistance to biotic and abiotic stress due to a lack of artificial selection, could be a valuable resource for breeding. These sources should be collected and preserved rather than abandoned (Percy, 2007). Although they are becoming more confined as derelict populations, perennial cottons related to the four known cultivated species are still maintained by local people for traditional uses such as pharmacopoeia, ritual practices, and particular textile uses in the semiarid regions of the tropics and subtropics. Successful collecting surveys have been done relatively recently in Senegal and Gambia, as well as in Cameroon and in Burkina Faso (Bèye, 1989; Bourgou et al., 2014; Seignobos and Schwendiman, 1991).

The Burkina Faso collection assembled more than 350 accessions representing diversity in photoperiod response, that is, photoperiod neutral (annual) and photoperiod sensitive (perennial), in Old World diploid cottons (*G. arboreum* and marginally *G. herbaceum*) and New World tetraploid cottons (*G. hirsutum* and *G. barbadense*). Accessions from *G. arboreum* exhibited the most intraspecific genetic diversity and genetic distance from the other species studied, whereas within *G. hirsutum* two types of accessions were distinguished: perennial and annual. Diversity observations were based on flowering and growth habit as well as molecular simple sequence repeat (SSR) analysis (Bourgou et al., 2014, 2016). Differences in ploidy between *G. hirsutum* and *G. arboreum*, as well as differences in flowering habit within *G. hirsutum*, will need to be overcome to realize full exploitation of the rich genetic diversity discovered within and among the species in this collection.

Cotton cultivated in Africa is exported almost in its entirety, and recently has been criticized for stagnation of its fiber quality (Estur, 2008). Although it is challenging to exploit this extensive collection, rich in diversity, for further enhancement of African cotton cultivars, it is essentital to continue to meet the changing needs and fiber quality demanded by the textile industry.

This current study evaluates some representative accessions of each species from the Burkina Faso collection in comparison to five cultivars from West African countries and Chad. The objectives are to 1) observe the comparative level of fiber quality components within the collection, and 2) identify accessions from the collection with fiber properties that have the potential to further enhance the quality of African cotton cultivars.

MATERIALS AND METHODS

Plant Material. Plant material was composed of five cultivars and 45 accessions. Cultivars are those currently grown in West African countries and Chad in 2010: H279-1 from Benin, N'TA L100 from Mali, A51 from Chad, and FK37from Burkina Faso (Bourgou and Sanfo, 2012). STAM 59A from Togo was included because it is routinely used as a regional reference or performance check cultivar in the breeding process. All these cultivars are *G. hirsutum*. Detailed characteristics are presented in Table 1. The accessions used in this study area are a subset of the 358 accessions collected in different agro-ecological areas of Burkina Faso between 2008 and 2010 (Bourgou et al., 2014). The subset was composed of the accessions deemed to be most representive of the four genetic diversity groups from the collection according to agromorphological (Bourgou et al., 2014) and molecular (SSR) evaluations (Bourgou et al., 2016), that is, 20 belonging to *G. hirsutum*, 14 to *G. barbadense*, 8 to *G. arboreum*, and 3 to *G. herbaceum*.

Table 1. Genotypes of cotton species evaluated at Farako-Bâ in 2011 and 2012

Plant material	Name	Origin	Year[z]	Species	Main characteristics
Cultivars	FK37	Burkina Faso	2001	*G. hirsutum*	Good yields, good fiber length and strength
	STAM 59A	Togo	1990	*G. hirsutum*	Average agronomical andfiber properties traits
	N'TA L100	Mali	2009	*G. hirsutum*	High hairiness, good agronomical and fiber quality traits
	H279-1	Bénin	2002	*G. hirsutum*	Good earliness and good yield in Benin cultivation environment
	A51	Tchad	1995	*G. hirsutum*	Good fiber length and maturity-fineness complex
Accessions	E7	Burkina Faso	2010	*G. hirsutum*	Annual, brown fiber
	E14	Burkina Faso	2010	*G. hirsutum*	Perennial, khaki fiber, small leaves and bolls
	E15	Burkina Faso	2010	*G. hirsutum*	Perennial, small leaves and bolls
	E17	Burkina Faso	2009	*G. hirsutum*	Perennial, small leaves and bolls
	E23	Burkina Faso	2009	*G. hirsutum*	Perennial tendency, earliness, high productivity, small bolls
	E28	Burkina Faso	2009	*G. hirsutum*	Annual, few or linterless
	E30	Burkina Faso	2009	*G. hirsutum*	Annual, great height, large bolls
	E31	Burkina Faso	2010	*G. hirsutum*	Perennial, small leaves and bolls
	E32	Burkina Faso	2010	*G. hirsutum*	Annual
	E37	Burkina Faso	2009	*G. hirsutum*	Perennial, small leaves and bolls
	E53	Burkina Faso	2009	*G. hirsutum*	Annual
	E1	Burkina Faso	2009	*G. barbadense*	Perennial, Broad leaves, conical bolls, kidney seeds
	E3	Burkina Faso	2010	*G. barbadense*	Perennial, small leaves, conical bolls, free seeds
	E10	Burkina Faso	2010	*G. barbadense*	Perennial, Broad leaves, conical bolls, kidney seeds
	E12	Burkina Faso	2009	*G. barbadense*	Perennial, Broad leaves, conical bolls, kidney seeds
	E18	Burkina Faso	2010	*G. barbadense*	Perennial, Broad leaves, conical bolls, kidney seeds
	E25	Burkina Faso	2009	*G. barbadense*	Perennial, Broad leaves, conical bolls, kidney seeds
	E35	Burkina Faso	2009	*G. barbadense*	Perennial, Broad leaves, conical bolls, free seeds
	E39	Burkina Faso	2010	*G. barbadense*	Perennial, Broad leaves, conical bolls, kidney seeds
	E13	Burkina Faso	2010	*G. arboreum*	Perennial, okra leaf, red flower, pyramidal bolls
	E29	Burkina Faso	2009	*G. arboreum*	Perennial, okra leaf, red flower, pyramidal bolls
	E33	Burkina Faso	2008	*G. arboreum*	Perennial, okra leaf, yellow flower, pyramidal bolls
	E38	Burkina Faso	2010	*G. arboreum*	Perennial, okra leaf, red flower, pyramidal boll
	E41	Burkina Faso	2010	*G. arboreum*	Annual, okra leaf, yellow flower, pyramidal bolls
	E43	Burkina Faso	2009	*G. herbaceum*	Perennial, okra leaf, pyramidal bolls

[z] Year of release/first cultivation (cultivars) or Year of collection (accessions)

Study Site. Experiments were conducted during 2011 and 2012 at the Agricultural Research Station of Farako-Bâ. This site is located in the western cotton production area of Burkina Faso, between the isohyets 800 and 1200 mm at 405 m of altitude, 4°20' W of longitude and 11°06' N of latitude. The soil type of the experimental area was ferasols with low clay and organic matter content, with a deficiency of nitrogen and phosphorus (Bado, 2002). South Sudanean climate is generally dominant with total annual precipitation of 831.5 mm for 73 rainy days in 2011 and 956 mm for 81 rainy days in 2012.

Experimental Design and Field Experiment. The experimental plot was arranged in a randomized complete block design with three replications separated from each other by a 2-m wide alley. In each replication, the 45 accessions and five cultivars were completely randomized and sown at the end of June each year. Each plot was 3 rows x 10 m. Hill-to-hill and row-to-row distance was the same at 0.80 m. The experimental plot was thinned to 2 plants/hill 2 wks after sowing to maintain a stand of 32,000 plants/ha^{-1}. All standard agronomic and plant protection practices were followed from sowing until harvest as recommended for cotton production in Burkina Faso (Bourgou and Sanfo, 2012; Bourgou et al., 2014).

Laboratory Testing and Variable Measurement. Total seed cotton of all the central row plants of each plot for each entry was hand-washed, harvested, and ginned with a laboratory roller gin. Percentage of fiber or lint (LP) was measured for each plot after ginning by dividing fiber weight by seed cotton weight * 100. Fiber properties were measured in 2011 by High Volume Instrument (HVI) of SOFITEX (Bobo-Dioulasso, Burkina Faso). Taking into account the quantity of 100 g of fiber required per entry by SOFITEX HVI, the five cultivars and only 25 accessions (11 *G. hirsutum*, 8 *G. barbadense*, 5 *G. arboreum*, and 1 *G. herbaceum*) produced enough lint to be analyzed by bulking fiber from all three replications. In 2012, the same process was used to harvest and prepare fiber samples for analysis on SOFITEX HVI and also on Cotton SA HVI (South Africa) as the latter required only 30 g fiber per entry.

Major fiber properties of interest—micronaire (Mic), maturity (Mat), length (UHML), uniformity (UI), short fiber content (SFC), strength (Str), elongation (Elo), degree of reflectance (Rd), and yellowness (+b)—were recorded as variables.

Statistical Analysis. The data collected were tested for differences in cultivars compared to accessions using analysis of variance (ANOVA) by SISVAR 5.1 Build 72 software. To do this, data recorded from each HVI analysis in 2011 and 2012 (HVI SOFITEX 2011; HVI SOFITEX 2012; HVI Cotton SA 2012) were considered as replications. The averages of the cultivars are compared to those of *G. hirsutum* accessions, followed by *G. barbadense* accessions, and then to those of *G.arboruem* plus *G. herbaceum*, using the Scott-Knott test, based on a 5% threshold.

RESULTS

Comparison Between Cultivars and *G. hirsutum* Accessions. Eleven *G. hirsutum* accessions were compared with five cultivars from Benin, Burkina Faso, Mali, Togo, and Chad. Results of the analysis of variance showed significant (UI and Str) to highly significant (LP, Mic, UHML, SFC, Elo, Rd, and +b) fiber quality differences (Table 2). Regarding LP, the studied cottons clustered into five significant difference groups. Accession E32 exhibited the highest LP at 46.1% but was in the same group with all cultivars plus accessions E53 and E30. Accessions E14, E23, E17, and E37, known as perennial types, produced the lowest LP.

The cultivars exhibited low Mic values, similar to accessions with an annual growth habit (Table 2). Conversely, E15, E31, E14, E37, and E17 exhibited high Mic at 6.5, 5.8, 5.4, 5.2, and 5.2, respectively, which perhaps is associated with their perennial tendency. For UHML, the best values came from accession E53 (29.79 mm) and Burkina Faso cultivar FK37 (29.68 mm) followed by accessions E32, E30, and Chad cultivar A51 at 28.14 mm. All other accessions and the Mali cultivar N'TA L100 produced UHMLs lower than the test mean of 26.06 mm. All accessions except E7 and E14 (colored fibers) and E15 and E37 (perennial cottons) produced UI values above the test mean and significantly higher than the cultivars except for cultivar FK37. STAM 59A, N'TA L100, A51, and H279-1 produced UIs below the test average value of 81.4%. All cultivars and most accessions grouped together with significantly lower SFC values. Accessions E7 (14.6%) and E15 (20.3%) exhibited significantly greater SFC than all other *G. hirsutum* genotypes tested. SFC is a measure of the percentage of fibers shorter than 12.7 mm, thus, accessions with the lowest UHML, such as E7 and E15, might be expected to exhibit higher SFC values (Table 2).

In terms of Str, only two genotypes, accessions E7 (212.0 kN m Kg^{-1}) and E28 (239.9 kN m Kg^{-1}) exhibited values below the test average (291.97 kN m Kg^{-1}). All of the remaining *G. hirsutum* accessions exhibited Str values as high as the cultivars, with the highest values from accessions E31 at 352.1 kN m Kg^{-1} and E37 at 326.7 kN m Kg^{-1} (Table 2). All *G. hirsutum* accessions exhibited Elo values significantly higher than all comparision cultivars except for cultivar H279-1. The best Elo values were from E15, E31, and E37, whereas A51, STAM 59A, FK37, and N'TA L100 had the lowest elongation values (Table 2).

Comparison Between Cultivated Cultivars and *G. barbadense* Accessions. When comparing *G. barbadense* accessions (8) to cultivars (5) in terms of fiber qualities, the analysis of variance results show significant to highly significant differences except for fiber maturity (Table 3). Results of ANOVA indicated that all of the cultivars were above 40% lint, whereas the most interesting G. barbadense accession (E3) was only 36.3%. All remaining accessions were under the mean value with the lowest value of 23.4% for E1.

Table 2. Lint percent and HVI fiber quality for fiveWest African countries and Chad cotton cultivars and 11 *G. hirsutum* accessions evaluated at Farako-Bâ in 2011 and 2012

Designation	LP[z] (%)	HVI measured fiber properties								
		Mic	Mat (%)	UHML (mm)	UI (%)	SFC (%)	Str (kN m Kg-1)	Elo (%)	Rd (%)	+b
E7	40.4 a_4[y]	4.5 a_1	85.0	22.57 a_2	78.5 a_1	14.6 a_2	212.0 a_1	8.9 a_3	35.5 a_1	20.3 a_3
E14	23.8 a_1	5.4 a_2	88.3	25.93 a_3	80.8 a_1	10.0 a_1	306.5 a_2	8.6 a_3	60.4 a_2	15.7 a_2
E15	28.9 a_2	6.5 a_3	88.3	20.98 a_1	78.6 a_1	20.3 a_3	308.3 a_2	10.4 a_4	74.7 a_3	9.1 a_1
E17	24.9 a_1	5.2 a_2	89.0	25.12 a_3	82.5 a_2	9.6 a_1	293.3 a_2	8.1 a_3	73.9 a_3	9.0 a_1
E23	24.6 a_1	4.6 a_1	86.7	25.38 a_3	81.8 a_2	9.0 a_1	283.6 a_2	8.9 a_3	68.7 a_3	7.4 a_1
E28	37.3 a_3	4.2 a_1	84.7	26.52 a_4	81.8 a_2	8.8 a_1	239.9 a_1	7.2 a_2	72.1 a_3	9.0 a_1
E30	42.7 a_5	4.5 a_1	87.7	28.00 a_5	84.1 a_2	6.8 a_1	297.0 a_2	7.6 a_2	74.3 a_3	9.5 a_1
E31	26.3 a_2	5.8 a_2	91.0	24.39 a_3	83.1 a_2	8.2 a_1	352.1 a_2	10.2 a_4	75.0 a_3	8.8 a_1
E32	46.1 a_5	4.3 a_1	88.0	28.87 a_5	85.5 a_2	6.6 a_1	289.8 a_2	6.7 a_2	71.5 a_3	8.8 a_1
E37	23.7 a_1	5.2 a_2	89.3	23.23 a_2	81.2 a_1	8.9 a_1	326.7 a_2	9.8 a_4	71.3 a_3	7.8 a_1
E53	43.5 a_5	4.5 a_1	89.0	29.79 a_6	83.4 a_2	7.2 a_1	306.1 a_2	6.5 a_2	73.3 a_3	8.3 a_1
FK37	43.6 a_5	4.2 a_1	87.3	29.68 a_6	81.6 a_2	8.8 a_1	303.9 a_2	5.3 a_1	75.3 a_3	8.7 a_1
STAM 59A	43.1 a_5	4.6 a_1	87.7	26.85 a_4	78.7 a_1	10.7 a_1	288.8 a_2	5.1 a_1	76.5 a_3	8.9 a_1
N'TA L100	43.3 a_5	4.8 a_1	87.7	25.15 a_3	79.4 a_1	10.7 a_1	276.4 a_2	5.4 a_1	75.3 a_3	9.5 a_1
H279-1	43.2 a_5	4.7 a_1	87.0	26.35 a_4	80.4 a_1	10.0 a_1	292.0 a_2	6.3 a_2	75.6 a_3	8.4 a_1
A51	41.5 a_5	4.4 a_1	87.3	28.14 a_5	80.3 a_1	9.1 a_1	295.3 a_2	4.9 a_1	74.4 a_3	9.5 a_1
Mean	36.1	4.8	87.7	26.06	81.4	9.9	292.0	7.5	70.5	9.9
CV (%)	4.9	9.1	3.2	3.38	2.1	15.2	8.8	13.3	4.8	7.6
Probability	0.0000 HS[x]	0.0000 HS	0.5664 NS	0.0000 HS	0.0003 S	0.0000 HS	0.0002 S	0.0000 HS	0.0000 HS	0.0000 HS

[z] LP = lint percent, Mic = micronaire, Mat = maturity ratio, UHML = upper half mean length, UI = uniformity index, SFC = short fiber content, Str = fiber bundle strength, Elo = elongation, Rd = reflectance, +b = yellow index.

[y] Means within a column followed by the same letter (a) and index number (a1 or a2 or a3, etc.) are not significantly different according to Scott-Knott test at p = 5% and form a same group. Difference between groups is significant (S) to highly significant (HS). Means with any letter (a) are not significantly different (NS).

[x] NS = not significant, S = significant at p = 0.05, HS = high significant at p = 0.01.

Most *G. barbadense* accessions had high Mic values compared with current cultivars, except for E10, which had the lowest Mic of 3.7 (Table 3). Mic among the *G. barbadense* accessions ranged from 3.7 to 5.6, which represents variation from 17% below to 25% above the means of the cultivars. Market standards for African cotton require Mic values to be between 3.8 and 4.2, with anything outside of that range being subject to a price reduction. No accessions and only one cultivar had a Mic in this range. Maturity values for *G. barbadense* accessions showed more diversity ranging from 88.3% to 96.0%, but were not different from the cultivars that did not vary more than 1% from one another (Table 3).

Fiber length analysis suggested that four *G. barbadense* accessions, E25 (31.09 mm), E1 (30.02 mm), E12 (30.02 mm), and E18 (28.92 mm), were significantly longer than the cultivars, except for cultivar FK37 at 29.68 mm (Table 3). Accession E39 and cultivar N'TA L100 exhibited the shortest UHML, both numerically below the test mean of 27.89 mm.

All cultivars had lower UI than the mean of the all *G. barbadense* genotypes tested (Table 3). The *G. barbadense* accessions all had UI values that suggested their value in fiber quality improvement except for accessions E39 and E3. The accessions exhibiting potential breeding value for UI also appear to be of interest for breeding to improve SFC.

Table 3. Lint percent and HVI fiber quality for five cotton cultivars and eight *G. barbadense* accessions evaluated at Farako-Bâ in 2011 and 2012.

Designation	LP[z] (%)	HVI measured fiber properties								
		Mic	Mat (%)	UHML (mm)	UI (%)	SFC (%)	Str (kN m Kg-1)	Elo (%)	Rd (%)	+b
E1	23.4 a_1[x]	4.4 a_1	88.3	30.02 a_3	84.0 a_2	7.7 a_1	324.5 a_2	7.1 a_2	72.7 a_1	9.3 a_1
E3	36.3 a_3	4.8 a_2	87.3	27.53 a_2	80.8 a_1	9.2 a_2	321.3 a_2	9.0 a_3	71.4 a_1	10.1 a_2
E10	24.8 a_1	3.7 a_1	90.7	27.04 a_2	82.8 a_2	7.8 a_1	329.4 a_2	7.1 a_2	68.9 a_1	11.9 a_3
E12	25.5 a_1	4.9 a_2	88.3	30.02 a_3	85.1 a_2	7.1 a_1	352.9 a_3	8.7 a_3	75.4 a_2	9.5 a_1
E18	24.8 a_1	5.0 a_2	89.0	28.92 a_3	83.6 a_2	7.1 a_1	381.8 a_3	6.8 a_2	72.2 a_1	9.6 a_1
E25	24.6 a_1	5.3 a_2	96.0	31.09 a_3	84.1 a_2	6.8 a_1	378.4 a_3	6.9 a_2	72.9 a_1	10.2 a_2
E35	31.5 a_2	5.1 a_2	88.3	27.81 a_2	83.3 a_2	7.7 a_1	329.5 a_2	9.1 a_3	70.9 a_1	10.7 a_2
E39	33.2 a_2	5.6 a_2	90.7	24.04 a_1	78.8 a_1	9.7 a_2	295.3 a_1	10.2 a_3	73.3 a_1	10.3 a_2
FK37	43.6 a_4	4.2 a_1	87.3	29.68 a_3	81.6 a_1	8.8 a_2	303.9 a_1	5.3 a_1	75.3 a_2	8.7 a_1
STAM 59A	43.1 a_4	4.6 a_1	87.7	26.85 a_2	78.7 a_1	10.7 a_2	288.8 a_1	5.1 a_1	76.5 a_2	8.9 a_1
N'TA L100	43.3 a_4	4.8 a_2	87.7	25.15 a_1	79.4 a_1	10.7 a_2	276.4 a_1	5.4 a_1	75.3 a_2	9.5 a_1
H279-1	43.2 a_4	4.7 a_1	87.0	26.35 a_2	80.4 a_1	10.0 a_2	292.0 a_1	6.3 a_2	75.6 a_2	8.4 a_1
A51	41.5 a_4	4.4 a_1	87.3	28.14 a_2	80.3 a_1	9.1 a_2	295.3 a_1	4.9 a_1	74.4 a_2	9.5 a_1
Mean	33.8	4.7	88.9	27.89	81.8	8.6	320.7	7.1	73.44	9.7
CV (%)	3.1	8.6	3.6	5.69	2.2	13.4	7.3	12.5	2.24	7.8
Probability	0.0000 HS[y]	0.0010 S	0.1246 NS	0.0004 HS	0.0011 S	0.0015 S	0.0001 HS	0.0000 HS	0.0002 S	0.0010 HS

[z] LP = lint percent, Mic = micronaire, Mat = maturity ratio, UHML = upper half mean length, UI = uniformity index, SFC = short fiber content, Str = fiber bundle strength, Elo = elongation, Rd = reflectance, +b = yellow index.

[y] Means within a column followed by the same letter (a) and index number (a1 or a2 or a3, etc.) are not significantly different according to Scott-Knott test at *p* = 5% and form a same group. Difference between groups is significant (S) to highly significant (HS). Means with any letter (a) are not significantly different (NS).

[x] NS = not significant, S = significant at *p* = 0.05, HS = high significant at *p* = 0.01.

All the accessions except E39 produced stronger fibers than those of the comparison cultivars (Table 3). The strongest fibers came from accessions E18, E25, and E12 with 381.8 kN m Kg^{-1}, 378.4 kN m Kg^{-1}, and 352.9 kN m Kg^{-1} Str values, respectively; whereas cultivars N'TA L100 (276.4kN m Kg^{-1}), STAM 59A (288.8kN m Kg^{-1}), and H279-1 (292.0 kN m Kg^{-1}) were the weakest. For Elo, all cultivars, except H279-1, had values less than those of the accessions. The best Elo values were found in accessions E39, E35, E3, and E12; well above the mean value of 7.1%. In terms of color grade, only accession E12 was similar to comparison cultivars, whereas E10 had the least desirable combination of reflectance and yellowness (Table 3).

Comparison Between Cultivars and *G. arboreum* Plus *G. herbaceum* Accessions. As with the *G. hirsutum* and *G. barbadense* species, comparisons between cultivars and *G. arboreum* (5) plus *G. herbaceum* (1) accessions revealed significant to highly significant differences for all fiber parameters except for UI (Table 4).

As with the tetraploid cultivars and accessions, higher coefficients of variation were associated with SFC, Elo, and Str, and to a lesser extent Mic than other traits measured (Table 4). These results indicate that cultivars possess numerically higher LP than either *G. arboreum* accessions or the *G. herbaceum* accession. Accession E29 (41.6%) of *G. arboreum* was similar to cultivar A51 (41.5%) from Chad. *G. herbaceum* accession E43 exhibited LP below the mean of the trial but the accession with the lowest LP was E38, a *G. arboreum* accession at only 24.6%. All *G. arboreum* accessions except E29, as well as the *G. herbaceum* accession had higher Mic values compared with the comparision cultivars. The highest Mic values were found for E38, E33, and E43; this level of Mic is outside the normal range of cultivated *G. arboreum* cotton. Analysis of Mat revealed that *G. arboreum* accessions E13, E33, and E38 were the most mature *G. arboreum* genotypes evaluated. It is known that traditionally *G. arboreum* and *G. herbaceum* cottons possess significantly shorter fibers compared with cultivated *G. hirsutum* cotton. This was confirmed for the *G. herbaceum* accession (E43 = 23.44 mm), but two *G. arboreum* accessions, E29 (26.31 mm) and E13 (26.08 mm) showed statistically similar UHML to cultivars STAM 59A (26.85 mm) and H279-1 (26.35 mm), better than N'TA L100 (25.15 mm) in Table 4.

In terms of Str, fibers from two *G. arboreum* accessions, E13 and E38 were significantly stronger compared with the cultivars and other accessions. The remainder of the diploid accessions were statistically similar to the comparision cultivars (Table 4). For Elo, all accessions exhibited higher values compared with *G. hirsutum* cultivars except for cultivar H279-1. *G. herbaceum* accession E43 exhibited the best Elo (10.0%) followed by *G. arboreum* E29 (7.7%) and E41 (7.2%). With regard to color grade, *G. herbaceum* accession E43 also possessed the best Rd/+b combination, similar to cultivars H279-1, STAM 59A, and FK37. Accession E38 had the least desirable color grade combination of low reflectance with high yellowness (Table 4).

Table 4. Lint percent and HVI fiber quality for five cotton cultivars and five *G. arboreum* plus one *G. herbaceum* accessions evaluated at Farako-Bâ in 2011 and 2012

Designation	LP[z] (%)	HVI measured fiber properties								
		Mic	Mat (%)	UHML (mm)	UI (%)	SFC (%)	Str (kN m Kg-1)	Elo (%)	Rd (%)	+b
E13	28.4 a_3[y]	5.9 a_2	96.3 a_2	26.08 a_3	80.6	6.8	376.0 a_2	6.0 a_2	67.0 a_2	11.9 a_3
E29	41.6 a_6	4.6 a_1	88.0 a_1	26.31 a_3	82.5	8.6	272.2 a_1	7.7 a_3	72.1 a_3	9.5 a_2
E33	25.9 a_2	6.8 a_3	94.3 a_2	24.67 a_2	80.8	10.6	305.2 a_1	6.5 a_2	69.3 a_2	10.1 a_2
E38	24.6 a_1	6.8 a_3	94.3 a_2	23.15 a_1	78.6	13.8	375.6 a_2	6.2 a_2	61.9 a_1	11.7 a_3
E41	30.6 a_4	5.9 a_2	90.7 a_1	23.01 a_1	80.4	10.9	307.1 a_1	7.2 a_3	67.1 a_2	9.5 a_2
E43[w]	35.8 a_5	6.6 a_3	87.0 a_1	23.44 a_1	80.7	9.4	320.8 a_1	10.0 a_4	77.3 a_3	8.3 a_1
FK37	43.6 a_7	4.2 a_1	87.3 a_1	29.68 a_5	80.4	8.8	303.9 a_1	5.3 a_1	75.3 a_3	8.7 a_1
STAM 59A	43.1 a_7	4.6 a_1	87.7 a_1	26.85 a_3	79.4	10.7	288.8 a_1	5.1 a_1	76.5 a_3	8.9 a_1
N'TA L100	43.3 a_7	4.8 a_1	87.7 a_1	25.15 a_2	80.3	10.7	276.4 a_1	5.4 a_1	75.3 a_3	9.5 a_2
H279-1	43.2 a_7	4.7 a_1	87.0 a_1	26.35 a_3	78.7	10.0	292.0 a_1	6.3 a_2	75.6 a_3	8.4 a_1
A51	41.5 a_6	4.4 a_1	87.3 a_1	28.14 a_4	81.6	9.1	295.3 a_1	4.9 a_1	74.4 a_3	9.5 a_2
Mean	36.5	5.4	89.8	25.71	80.4	9.9	310.3	6.4	72.0	9.6
CV (%)	1.9	6.6	3.0	3.15	2.2	15.6	8.9	9.7	2.2	5.9
Probability	0.0000 HS[x]	0.0000 HS	0.009 S	0.0000 HS	0.2910 NS	0.0044 S	0.0013 S	0.0000 HS	0.0000 HS	0.0000 HS

[z]LP = lint percent, Mic = micronaire, Mat = maturity ratio, UHML = upper half mean length, UI = uniformity index, SFC = short fiber content, Str = fiber bundle strength, Elo = elongation, Rd = reflectance, +b = yellow index.

[y]Means within a column followed by the same letter (a) and index number (a1 or a2 or a3, etc.) are not significantly different according to Scott-Knott test at p = 5% and form a same group. Difference between groups is significant (S) to highly significant (HS). Means with any letter (a) are not significantly different (NS).

[x]NS = not significant, S = significant at p = 0.05, HS = high significant at p = 0.01.

[w]E43 is the *G. herbaceum* accession.

DISCUSSION

For many years, African cotton cultivars produced consistent fiber quality for the current market; but dependence on a limited number of cultivars, and erosion of genetic resources and breeding program support raises concerns about the ability for further enhancements to address evolving markets and environments.

African cotton cultivars possess intrinsic fiber qualities in UHML and Str when combined with manual harvesting that obtain favored status in the international market (Bourgou and Sanfo, 2012 ; Estur, 2008; UEMOA, 2006). In this study, cultivars from Burkina Faso (FK37), Benin (H279-1), and to a lesser extent Chad (A51) confirm this status, being consistently at least average for all fiber properties evaluated. These cultivars are far from perfect and each cultivar was launched either alone or with only one other cultivar choice and has been commercially cultivated for 15 to 26 years (Table 1). The result is fiber quality improvements over these last few years has lagged compared to competing cotton from other countries (Estur, 2008). Accessions from the Burkina Faso collection exceeded some cultivars for certain fiber properties, even key ones.

More than 98% of African cotton is exported, so a perpetual need exists to create new cultivars with enhanced fiber quality. Raw material can represent from 50 to 70% of textile processing costs, so consistent, high quality fiber and stable price is critical (Chakraborty et al., 2000). Fiber properties are at least moderately heritable, allowing successful improvement of cotton fibers through breeding; modified from coarse textured, short length types into cultivars with properties meeting modern textile industry requirements (Lançon et al., 1990; May, 2003). Because it was previously reported that the African cotton breeding gene pool is ageing and increasingly devoid of the alleles necessary to meet the current breeding challenges, it has been suggested that new genes of interest in the local germplasm should be collected and evaluated for the ability to impact fiber quality (Bourgou and Sanfo, 2012; N'Doye et al., 2011).

This study focused on looking for high fiber quality values in locally collected germplasm resources to potentially enhance cultivar development. Native feral cottons are tempting to exploit for breeding purposes as they possess extensive adaptability and high resistance to biotic and abiotic stress; they also have some adaptation to regional stresses and even some human domestication and, thus, are a valuable resource for breeding (Boopathi et al., 2014; Van Esbroeck and Bowman, 1998). When comparing cultivars to accessions, the objective was to look for potential parent material within the accessions with appealing fiber quality traits that could be used to enhance the long-popularized adapted cultivars.

With regard to the current experimental results, more *G. hirsutum* accessions appeared similar to the current cultivars (as they are the same species) and presented the most fiber qualities that meet current textile industry standards, even if dispersed through many accessions. It is apparent that accession E32 with LP of 46.1% could contain valuable alleles for LP and could theoretically improve current cultivars by 2.5 to 4.6 percentage points. Two accessions, E32 and E53, presented above average UHML and could possibly be used to increase UHML, as they were longer than four of the comparision cultivars**.** Accession E32 and E30 both show potential to improve SFC by as much as a 4 percentage point reduction.

Our collection also included colored fiber *G. hirsutum* cottons, represented in this current experiment by E7 and E14, with brown and khaki colored fibers. Previous collections in Africa—Cameroon (Seignobos and Schwendiman, 1991), Senegal, and Gambia (Bèye, 1989) did not report colored cottons, although worldwide many collections report them, including among *G. hirsutum* accessions (Abdurakhmonov et al., 2008; Ulloa et al., 2006), *G. arboreum* accessions (Boopathi et al., 2014; Singh et al., 1993), and *G. barbadense* accessions (Carvalho et al., 2014). With these particular cottons, it is possible to develop niche markets, as there is a growing interest in naturally colored conventional or organic cotton fibers. This type of cotton offers interesting, perhaps environmentally friendly, opportunities in that it allows processing naturally colored clothing with mitigation of chemical use in the treatment (bleaching, dyeing, etc) of textile products. Similar to the accessions within our collection, it is recognized that colored cotton accessions generally produce inferior fibers for the regular yarn market. At the same time, it is straightforward to develop colored cotton cultivars with improved spinning quality via hybridization with elite white fiber cultivars followed by selection of appropriate natural colored cotton fiber qualities (Basbag and Gencer, 2007). All these reasons rationalize the existence of a valued colored cotton niche in well confined areas in India and semiarid Brazilian Northeast, specifically produced as organic cotton (Carvalho et al., 2014; Singh et al., 1993).

As in previous studies, *G. barbadense* accessions had lower LP and higher seed weight (Hau, 1996), but they also exhibited positive attributes such as UHML, Str, Elo, and SFC, which are the more important cotton fiber properties for the global spinning market (Table 3). Three accessions E25, E1, and E12 had better UHML than comparision cultivars except for cultivar FK37. In terms of Str, all *G. barbadense* accessions, especially E18, E25, and E12 showed significantly higher tenacity than all comparision cultivars. For example, E18 exceeded the comparison cultivars by 8.0 to 9.5 kN m Kg^{-1}(Table 3). With regard to Elo and SFC, many *G. barbadense* accessions were better than the comparision cultivars and it was specially noted that accession E25 combines desirable UHML, Str, and SFC.

Our results agree with those of the previous study conducted by Bèye (1989) that ranked his collection of *G. barbadense* accessions as having lower Mic and better Elo (*G. barbadense* race *brasilense*) or higher Mat, lower Mic, and better Elo (*G. barbadense* race *barbadense*). *G. barbadense* is well known as having longer fibers, also called extra-long staple, stronger fibers, and finer fibers and is widely cultivated worldwide or utilized as parental breeding material to enhance fiber quality in other species (Basbag and Gencer, 2007; Boopathi et al., 2008; Percival et al., 1999). Because of its dry climate and irrigation possibilities offered by the Nile Valley, Egypt is one of the few countries still industrially cultivating *G. barbadense* cottons under the label “Egyptian cotton,” an exceptional fiber length niche and profitable market (Abdalla et al., 2001). The U.S. produces *G. barbadense* under the common name American Pima.

G. arboreum accessions offered fewer traits of interest for the improvement of cultivars. This species traditionally has been accepted for only some textile products and is characterized by coarse and short fibers (Bardak and Bolek, 2012; Gotemare and Singh, 2004). In this study, *G. arboreum* accession E29 exhibited LP equal to cultivar A 51, accessions E29 and E13 had UHML comparable to N’TA L100, and accession E13 produced stronger fibers than all of the cultivars evaluated (Table 4). As with *G. arboreum* accessions, *G. herbaceum* (E43) was outstanding for Str. This characteristic is widely recognized as the most important fiber trait found in the diploid species (Bardak and Bolek, 2012; Gotemare and Singh, 2004; Kantartzi et al., 2009), although the diploid species are inherently weak in terms of LP, UHML, and Elo, which certainly has been disadvantageous when competing in commercial cultivation with *G. hirsutum* even in their own areas of origin, that is, Africa and Asia (Hutchinson, 1949; Gotemare and Singh, 2004). Despite improvement efforts in India, up until 1998 pure diploid cultivars produced approximately 38 to 40% lint and 24 to 25 mm UHML (Singh and Kairon, 2014). Regardless, diploid cottons are still valued in Asian countries, especially India, where there is an active local and qualified crafts outlet for this type of cotton (Boopathi et al., 2014). They are mainly used as parental material with *G. hirsutum* parents to produce high valued hybrids such as Deviraj and Devitej from the introgression of *G. hirsutum* alleles (Boopathiet al., 2014; Gotemare and Singh, 2004; Singh and Kairon, 2014).

CONCLUSIONS

Local germplasm should be exploited for improving breeding and expanding the genetic base and level of variabilty in current breeding programs. This study, comparing cultivars from West African countries and Chad to feral cottons locally collected in Burkina Faso, has demonstrated that these accessions contain fiber quality alleles that could improve the fiber quality of African cultivars, including LP. Potential promising characters or character combinations for improving cultivars were LP, SFC, and, to a lesser extent, UHML and Elo from *G. hirsutum* accessions; UHML and Str from *G. barbadense* accessions; and Str from the diploid (*G. arboreum* and *G. herbaceum*) accessions. With *G. hirsutum* accessions, it is also possible to breed naturally colored cottons (khaki or brown). To exploit this potential, a research-based breeding and selection program needs to be devised and managed, first to identify the most promising donor genotypes with minimum undesirable genes or gene combinations, and second, develop strategies to overcome possible crossing barriers. Introgression of genes from accessions not only offer the potential for enhancing quality to maintain the good reputation of African cotton in an increasingly competitive global fiber market, but it also promises to reinvigorate declining variability in available genetic resources, and develop new elite germplasm from which to launch a pipeline of improved cultivars to respond to dynamic markets and climates.

REFERENCES

Abdalla, A.M., O.U.K. Reddy, K.M. El-Zik, and A.E. Pepper. 2001. Genetic diversity and relationships of diploid and tetraploid cottons revealed using AFLP. Theor. Appl. Genet. 102:222–229.

Abdurakhmonov, I.Y., R.J. Kohel, J.Z. Yu, A.E. Pepper, A.A. Abdullaev, F.N. Kushanov, I.B. Salakhutdinov, Z.T. Buriev, S. Saha, B.E. Scheffler, J.N. Jenkins, and A. Abdukarimov. 2008. Molecular diversity and association mapping of fiber quality traits in exotic *G. hirsutum* L. germplasm. Genomics. 92:478–487.

Bado, B.V. 2002. Rôle des légumineuses sur la fertilité des sols ferrugineux tropicaux des zones guinéenne et soudanienne du Burkina Faso. Thèse de Doctorat, Université de Laval, Québec, Canada.

Bardak, A., and Y.Bolek. 2012. Genetic diversity of diploid and tetraploid cottons determined by SSR and ISSR markers. Turkish J. Field Crops. 17(2):139–144.

Basbag, S., and O.Gencer. 2007. Investigations of some yield and fiber quality characteristics of interspecific hybrid (*Gossypium hirsutum* L. x *Gossypium barbadense* L.) cotton varieties. Hereditas. 144:33–42.

Berti, F., J.L.Hofs, H. S.Zagbai, and P.Lebailly. 2006. Le coton dans le monde, place du coton africain et principaux enjeux. Biotechnol. Agron. Soc. Environ. 10(4):271–280.

Bèye, A.M. 1989. Etude des cotonniers sub-spontanés du Sénégal et de la Gambie: Identification de quatre types de cotonniers, UNIVAL, ISRA.

Boopathi, N.M.,A. Gopikrishnan, N.J.Selvam, R. Ravikesavan, K. Iyanar, S. Muthuraman, and N. Saravanan. 2008. Genetic diversity assessment of *G. barbadense* accessions to widen cotton (*Gossypium* pp.) gene pool for improved fibre quality. J. Cot. Res. Dev. 22(2):135–138.

Boopathi, N.M., S. Sathish, P. Dachinamoorthy, P. Kavitha, and R. Ravikesavan. 2014. Usefulness and utilization of Indian cotton germplasm. World Cotton Germplasm Resources. Available online at http://dx.doi.org/10.5772/58619 (verified 30 April 2018).

Bourgou, L., and D. Sanfo. 2012. Potential genetics benefits of using Brazilian cotton varieties to improve those cultivated in the C4 countries: 1. Analysis of major architectural and agronomic characteristics. Tropicultura. 30(4):243–248.

Bourgou, L., W.V. Tarpaga, M. Sawadogo, D. Sanfo,and J.D. Zongo. 2014. Préservation de la diversité génétique dans le genre *Gossypium* au Burkina Faso: Collecte et évaluation préliminaires de cotonniers locaux. Int. J. Biol. Chem. Sci. 8(5):2081–2094.

Bourgou, L., M. Sawadogo, D. Sanfo, and J.M.Lacape. 2016. SSR-based genetic diversity of traditional and perennial cotton (*Gossypium* spp.) populations collected in Burkina Faso. Genet. Resour. Crop Evol. 64(7):1743–1759. DOI 10.1007/s10722-016-0470-4.

Carvalho, L.P., F.J.C. Farias, L.M.M. de Andrade, and J.I.da Silva Rodrigues. 2014. Inheritance of different fiber colors in cotton (*Gossypium barbadense* L.). Crop Breeding Appl. Biotech. 14:256–260.

Chakraborty, K., D. Ethridge, and S. Misra. 2000. How different quality attributes contribute to the price of cotton. p. 374–377 *In* Proc. Beltwide Cotton Conf., San Antonio, TX. 4-8 Jan. 2000. Natl. Cotton Counc. Am., Memphis, TN.

Estur, G. 2008. Organisation et performances des filières cotonnières africaines: qualité et commercialisation du coton fibre en Afrique. Document pour la Banque Mondiale.

Gotemare, V. and P. Singh. 2004. Use of wild species for cotton improvement in India. ICAC Rec., XXII:12–14.

Hau, B. 1996. La sélection Cirad sur *G. hirsutum*. 2ème Journées Programme coton, 7ème Atelier Génétique-Technologie.

Hussein, K., C. Perret, et L. Hitimana. 2005. Importance économique et sociale du coton en Afrique de l’Ouest : Rôle du coton dans le développement, le commerce et les moyens d’existence. Secrétariat du CSAO, Paris.

Hutchinson, J.B. 1949. The dissemination of cotton in Africa. Empire Cotton Growing Rev. 27(123):466.

Kantartzi, K.S., M. Ulloa, E. Sacks, and J.McD.Stewart. 2009. Assessing genetic diversity in *Gossypium arboreum* L. cultivars using genomic and EST-derived microsatellites. Genetica. 136:141–147.

Lançon, J., J.L. Chanselme, and C. Klassou. 1990. Bilan du progrès génétique réalisé par la recherche cotonnière au Nord-Cameroun de 1960 à 1988. Cotton Fib. Trop. 45(2):145–167.

May, O.L. 2003. Breeding Cotton With Enhanced Fiber Qualities Amidst Technologically Evolving Yarn and Textile Manufacturing Industries. 62nd Plenary Meeting of the International Cotton Advisory Committee. 7-12 September 2003. Gdansk, Poland.

N’doye, O., H. Roy-Macauley, M.D. Faye, A. Sangare, et P. Sérémé. 2011. La recherche cotonnière en Afrique de l’Ouest et du Centre. Glocal revue africaine sur le commerce et le développement, N° 4 mars-avril, Numéro spécial sur le coton.

Percival, A.E., J.F. Wendel, and J.M. Stewart. 1999. Taxonomy and germplasm resources. p. 33–63 *In* C.W. Smith and J.T. Cothren (eds.), Cotton Origin, History, Technology, and Production. John Wiley & Sons, Inc., New York, NY.

Percy, R.G. 2007. *Gossypium* Germplasm Resources for Cotton Improvement. The World Cotton Research Conference-4. 10-14 September 2007. Lubbock, TX.

Seignobos, C., and J. Schwendiman. 1991. Les cotonniers traditionnels du Cameroun. Cotton Fib. Trop. 46(4):309–322.

Singh, P., and M.S. Kairon. 2014. Cotton Varieties and Hybrids. CICR Tech. Bull. No:13.

Singh, V.V., S.S. Narayanan, V.M. Kulmethe, G.R. Anap, and S.N.Nagwekar. 1993. A brief review on coloured linted cotton documenting selected genotypes of *G. hirsutum* L. J. Indian Soc. Cot. Improv. 18:91–94.

UEMOA. 2006. Standards “Afrique” de qualité du coton fibre. p. 40 *In* Manuel qualité pour les filières UEMOA. Guide technique No. 3, Ver. 1.

Ulloa, M., J.M. Stewart, C.E.A. Garcia, S. Godoy-Avila, M.A. Gaytan, and N.S.Acosta. 2006. Cotton genetic resource in the western states of Mexico: In situ conservation status and germplasm collection for ex situ preservation. Genet. Res. Crop Evol. 53:653–668.

Van Esbroeck, G.A., and D.T. Bowman. 1998. Cotton germplasm diversity and its importance to cultivar development. J. Cotton Sci. 2(3):121–129.

Wendel, J.F., C.L. Brubaker, and T. Seelenan. 2010. The origin and evolution of Gossypium. p. 1–18 *In* J.M. Stewart, D.M. Oosterhuis, J.J. Heitholt, and J.R. Mauney (eds.). Physiology of Cotton. Spinger, Dordrecht, Germany..